ROYAL COMMISSION ON FARM MACHINERY

RESEARCH AND DEVELOPMENT IN THE FARM MACHINERY INDUSTRY

Alex G. Vicas

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RESEARCH AND DEVELOPMENT IN THE FARM MACHINERY INDUSTRY

by

Alex G. Vicas

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What economic policies will foster the optimal flow of inventions and innovations in farm machinery?

To help answer this question, this study attempts to define some of the problems associated with technological change in farm machinery. Basic data on the identity of the inventor, the process of inventing, the role of innovation in competition, the effects of new machinery on agriculture, and on how all of these are changing over time -- this information is presently not available to the decision-maker, who must decide on economic policy.

The whole question is complicated by the rudimentary state of the economist's knowledge concerning the intricate network of relationships linking technological change to the variables that define the performance of the economy. Jacob Schmookler has called technological change "the *terra incognita* of modern economics".[1/] In recent years, a large number of economists have become preoccupied with problems of technological change.

Traditionally, the economist recognized the existence of technological change, and then dealt with it by relegating it to the box labelled *ceteris paribus*, the catchall for the variables that are exogenous to the model. The recognition that technological change not only responds to economic stimuli, but that it is becoming increasingly important in explaining the performance of the economy, no longer permits the economist to be blasé about technological change. The magnitude of the resources allocated to inventive activity has become increasingly important. Expenditures on industrial research and development in the United States grew from $3.6 billion in 1953 to more than $16 billion in

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1/ Jacob Schmookler, Invention and Economic Growth, Cambridge, Mass.: Harvard University Press, 1966, p. 3.

1966.[2/] Similar expenditures in Canada increased from $51.4 million in 1955 to $235.0 million in 1965.[3/] The dramatic nature of the growth of research and development is highlighted by the following: more than 40 per cent of Canadian firms with research and development units in 1964 reported that they had established their first permanent research and development unit only since 1960.[4/]

The recent literature in economics has witnessed an outpouring of articles and books dealing with technological change and its various aspects. In this essay, some of these techniques of analysis will be applied for the first time to farm machinery, and we shall develop new techniques to deal with other problems.

Some of the theoretical issues are introduced in this chapter through a discussion of a number of conceptual problems. What is an invention? What constitutes an innovation? What is diffusion? What is the product life cycle? These are the basic concepts that will be used extensively in the analysis to follow.

The Concepts of Invention and Inventing

Farm machinery has obviously changed over time, and presumably there is some process whereby the present machinery was invented. Any attempt to describe the process of inventing in terms of discrete inventions, however, produces a number of conceptual problems. Several individuals both in government and industry repeatedly emphasized during interviews that farm machinery is not "invented", that it evolves over time.

2/ The figures include research and development performed by the industrial sector, whether financed by the firm, government or others. The 1953 figure is from National Science Foundation, Research and Development in Industry 1960: Final Report of a Survey of R&D Funds and R&D Scientists and Engineers, Washington: U.S. Government Printing Office, 1963, p. 7. The 1966 figure is based on "U.S. Research Spending Off", The Financial Times, January 9, 1967, p. 9.

3/ Dominion Bureau of Statistics, Industrial Research and Development Expenditures in Canada, 1965, Catalogue No. 13-527, Ottawa: Queen,s Printer, p. 14.

4/ Dominion Bureau of Statistics, Industrial Research and Development Expenditures in Canada, 1963, Catalogue No. 13-524, Ottawa: Queen,s Printer, p. 12.

The human mind has a natural preference for reducing observed phenomena into discrete units and placing these units into well-labelled conceptual boxes. The only major attempt to deal with inventing as a continuous evolutionary process dates back to the 1930s.[5/] Gilfillan studied the invention of the ship, tracing back various features to the aborigine holding on to a log as he swam. Gilfillan concluded that the whole invention of the ship, from floating log to modern motor vessel, occurred without a single major invention. The whole evolutionary process consisted of innumerable small improvements and modifications. For example, Gilfillan summarizes the inventive process as it applied to sailing ships between 1706 and 1935 as follows:

> In this period, without inventions aboard her, she was transformed in appearance, transmuted into steel, doubled in speed, ten-folded in size, greatly bettered in seaworthiness, comfort and durability, canonized in literature and painting, because now glorified in beauty -- and all merely by little increments of change in size and proportions, and by adopting materials and machinery invented elsewhere, and by making insignificant inventions on herself, like adding a fourth and fifth mast on long ships, or making two sails of the unwieldy topsail. She is an egregious instance of how inventive progress marches on for the most part without difficult or cardinal inventions.[6/]

Apart from Gilfillan's sociological study, this type of evolutionary process of invention has received scant attention. Those subscribing to the evolutionary concept of inventing as being applicable to farm machinery point to the nature of the changes that have occurred. Tractors and combines have become larger and more powerful, and the implements used with these tractors have increased in size and capacity. Improved systems of controls have become critical with the increased size (witness the evolution of hydraulic systems on tractors). All these changes have been evolutionary, with few if any well-defined inventions. The other changes, also, have been primarily evolutionary -- for example, the adoption of new materials or new

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5/ S. C. Gilfillan, Inventing the Ship, Chicago: Follett Publishing Co., 1935.

6/ Ibid., p. 156.

components. A dry-type air filter adapted and applied to a combine engine eliminates the need for daily service. This is certainly not a revolutionary change; perhaps it does not even qualify to be labelled an invention. The cumulative effect of a large number of such improvements, however, may increase productivity substantially. With this type of inventive process, it becomes difficult to talk in terms of an invention or an inventor. As Gilfillan put it,

> So that foolish question of who invented the steamship, we shall certainly not answer by any such asininity as 'Fulton'. We might best reply, as before, that it was never invented, but is still being invented,... like clothes or modern agriculture.7/

The question arises whether it is desirable for technological change to proceed in discrete and revolutionary states. Fritz Machlup raises the following possibility: "It may well be that the sum total of all minor improvements, each too small to be called an invention, has contributed to the increase in productivity more than the great inventions have."8/

A number of specific inventions have the appearance of being discrete events. Even these inventions, however, are often the result of a long series of starts by different would-be inventors. The event which appears ultimately as "the invention" may be nothing more than the first member of a long family of new products which is commercially successful.

The corn combine and the "no-tillage" planter9/ are examples of this continuous type of inventing. Efficient versions of a corn combine became available about 1958, and corn combines with "on-the-go" adjustments, in 1961. As far back as the early 1930s, farmers began experimenting by placing a conventional corn picker in front of a grain combine and feeding corn into the combine by hand. Combines with corn-picker attachments were manufactured by

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7/ Ibid., p. 196.

8/ Fritz Machlup, The Production and Distribution of Knowledge in the United States, Princeton: Princeton University Press, 1962, p. 164.

9/ The "no-tillage" planter is also known as the "zero tillage" planter. It involves combining the operations of applying herbicides and fertilizer and planting.

various small-line companies from time to time. The University of Illinois did some research on a corn combine. The John Deere Company and Allis-Chalmers became interested in corn combines during the early 1950s, with John Deere concentrating on the problem of getting corn into the combine, and Allis-Chalmers on the problem of the internal workings of the combine. Who invented the corn combine?

If we adopt one definition -- "Invention is the stage at which the scent is first picked up, development the stage at which the hunt is in full cry."[10/] -- then we must conclude that the corn combine was the invention of an anonymous farmer experimenting with a corn picker in front of a combine. Schmookler adopts a similar definition.[11/] He dichotomizes the inventive process into two stages -- the formation of the essential properties of a novel product or process (invention) and subsequent refinements (development). In the case of the corn combine, anonymous farmers were responsible for both the invention and the initial development, whereas university and industrial researchers were responsible for the subsequent refinements which allowed the corn combine to be commercially successful. These definitions of "invention" and "development" are adopted in the subsequent analysis.

The initial inventions in farm machinery often involve merely a rearrangement or a new combination of known components. The tiller-combine, for example, involved mounting a seed box on a plow; the no-tillage corn planter involved a combination of implements to open a furrow, place a seed, and apply fertilizers and herbicides in one operation. The initial invention is often the result of individual effort, while the subsequent refinements -- improved control over the operation (for example, more precise placing of fertilizer in relation to seed); increased versatility (application to new crops or a wider range of field conditions); increased ease of operation and adjustment; longer durability -- these refinements are typically the work of the industrial research laboratory.

10/ John Jewkes, David Sawers, and Richard Stillerman, _The Sources of Invention_, London: Macmillan & Co. Ltd., 1958, p. 18.

11/ Schmookler, _op. cit._, pp. 8-9.

The division of labour between the individual inventor and the research laboratory has been observed in a large range of different industries.[12/] The work of development is often more routine, more expensive, and requires different skills than the work of conceiving the novel product. The industrial researcher may well behave according to his comparative advantage by specializing in development more than in inventing. The statement that industrial research units tend to specialize in development rather than invention in no way diminishes the prestige or importance of their work. The benefits made possible by the initial invention would not be realized without this development work.

The next chapter will look at the inventive process as it applies to farm machinery. The following questions will be considered: Who is the inventor? What is the division of labour between inventors and researchers responsible for the subsequent development? How is this division of labour changing over time?

The analysis of inventive activity can be cast into the framework of a product life cycle.[13/] This concept is used by marketing analysts to describe the history of a new product as it progresses through various historical stages. This simple concept is useful in providing a method for relating the different problems analyzed in this study. The commercial history of a product is divided into a number of different periods from the initial conception of the new product to the final stage where only replacement sales are made, and the product is gradually displaced by new products introduced into the market. The term "gestation period" may be used to describe the process of invention and initial development. This period may include a number of abortive attempts to market the new product.

Innovation and the Close Period

The new agricultural implement is eventually developed to the point where it is ready to be marketed. The innovating firm may

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12/ D. Hamberg, "Invention in the Industrial Research Laboratory", Journal of Political Economy, April 1963, pp. 95-115.

13/ The concept of a product life cycle used here borrows heavily, with amendments, from Theodore Levitt, "Exploit the Product Life Cycle," Harvard Business Review, November-December 1965, pp. 81-94.

be already established in the farm machinery industry, or a new firm may be created, Schumpeterian style, to exploit the market possibilities of the new product. During the early stages of marketing, the innovator does not face direct competition. This stage of the product cycle is called the close period.[14/] During this stage, the innovator has to create a market for the product. The innovator goes through a period where his attempts to entice buyers to try his product are extremely expensive, his sales volume is low, and the possibility of failure is relatively high. The efforts required to establish the product may vary directly with the degree of novelty of the product. As Levitt puts it, "The world does not automatically beat a path to the man with the better mousetrap. The world has to be told, coddled, enticed, romanced, and even bribed....[15/]

There may be a strong incentive to make evolutionary changes rather than high-risk revolutionary changes in the characteristics of products. Certain firms may even adopt the conservative policy of letting others introduce the radical innovations, hoping to follow as soon as the new product is established. The history of farm machinery abounds with new products that were not successful. Similar products are often reintroduced successfully at another date. John Bean (FMC), for example, introduced a hay conditioner in the late 1940s.[16/] Hay conditioners were introduced successfully only in the late 1950s. The manner in which development of both the product and the market for the product are attempted has an important influence in determining whether the product will be successful.

The product may be new in two different ways: it may be new in its function or only in its appearance.[17/] Products that are

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14/ J. R. Hicks, "The Process of Imperfect Competition", Oxford Economic Papers, February 1954, p. 41.

15/ Levitt, op. cit., p. 84.

16/ A hay conditioner crushes the straw and thus allows the straw to dry more quickly. The variation in drying time for different parts of the straw is reduced, and thus more feed can be obtained, in addition to saving on drying time.

17/ Robert Reichardt, "Competition through the Introduction of New Products", Zeitschrift für Nationalökonomie, 1962, p. 42.

new in their function may be further subdivided into three categories: those that have a new function -- for example, a hay waferer;[18] those that have a radically new technique for performing an old function -- for example, a "no-tillage" corn planter; and those that have a novel technique for performing an old function that is sufficiently new for the user of the machine to talk about switching to the new product -- for example, a double-swath windrower or a tractor with a weight-transfer device.[19]

The purchase of a new type of implement by the agribusinessman can be decomposed into the purchase of a number of constituent characteristics.[20] The buyer may be regarded as purchasing a cost reduction, increased convenience, insurance against the uncertainties of the labour market, mechanical breakdown, or weather at critical periods, increased comfort for the operator (especially relevant when the owner operates the machinery himself), prestige in the local community (conspicuous consumption), or some combination of these factors.

The innovation differs from the invention in that it consists of making the new product or the improvement available in the market place. Invention and development are in effect preconditions for the product innovation. A number of questions arise concerning this process of innovation. To what extent do inventors set up new firms to exploit the new product? To what extent do the innovators consist of firms already established in the industry? To what extent do the innovators consist of firms that are already established in industries other than the farm machinery

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18/ A hay waferer is a machine that presses hay into wafers. Heat generated in the process "cooks" the wafer. Hay wafers can be handled more conveniently in the barn than the usual methods of handling hay in bales.

19/ A double-swath windrower simply picks up two swaths simultaneously to lay a windrow. This implement offers advantages when crop yields per acre are low. A weight transfer device on tractors transfers weight from the implement and the front of the tractor to the rear wheels, thus permitting the tractor operator to control the implement more precisely and to obtain increased traction as needed.

20/ Kelvin J. Lancaster, "A New Approach to Consumer Theory", Journal of Political Economy, April 1966, pp. 132-157.

industry? Are there trends over time in the composition of the innovators? What factors explain the composition of the innovating firms?

Product Diffusion and the Invasion Period

If the new product is commercially successful, the innovator is likely to earn substantial profits. In the absence of barriers to entry, knowledge of the profits earned by the innovator will attract entry into the market for the new product. The innovator thus "... leads in the sense that he draws other producers in his branch after him. But as they are his competitors, who first reduce and then annihilate his profit, this is, as it were, leadership against one's will."[21/] New firms invade the market for the new product. This stage of the product cycle is called "the invasion period". The term "product diffusion" is used to describe the process whereby the innovator's new product is imitated and added to the catalogues of other firms. These imitations may be produced under licence if the invention was patented, or they may result from research and development to produce an implement performing the same functions, but differing from the innovation in detailed characteristics.

The term "diffusion lag" may be applied to describe the interval of time between the marketing of the innovation and the competitive response of other firms in the industry. Time is required for the would-be entrant to become aware of the innovation and to evaluate whether it appears worthwhile to respond with a similar product. Once a decision to market a competitive product has been made, time is required to build and test prototypes and to set up manufacturing facilities. The length of time that elapses before competitive products appear in the market may vary greatly from one case to another.

The diffusion lag affects the extent to which social benefits are derived from innovations.[22/] The innovator is usually able to

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21/ Joseph A. Schumpeter, trans. Redvers Opie, The Theory of Economic Development, Cambridge, Mass.: Harvard University Press, 1934, p. 89.

22/ Fritz Machlup, "The Optimum Lag of Imitation Behind Innovation", Til Frederik Zeuthen, 9 September 1958, Copenhagen: Nationalokonomisk Forening, 1958, pp. 239-56.

earn above-normal profits during the closed period, and to some extent during the invasion period. The profits earned by the innovator vary directly with the length of the diffusion lag. The rate of innovation, however, depends not on the profits of innovating *per se*, but on the rewards for innovating in relation to the rewards that the potential innovator could get by doing something else. If the diffusion lag is infinitely long, the innovator may enjoy a high rate of profit and thus have little incentive to turn his attention from managing a highly profitable business towards further innovation. Competition from new entrants into the market may provide an incentive for the innovator to try to increase, or at least protect, his profits by innovating again. If the diffusion lag is very short, on the other hand, the reward for innovating may not provide sufficient incentive to induce innovations.

There is some finite lag at which the rate of flow of innovations is maximized. The economy, however, benefits from the availability of innovations, and not from their mere existence. Competition among firms producing similar products is likely to increase the availability of, or accessibility to, the new product. The maximum benefits to society from a *given* rate of innovation are realized when there is no diffusion lag.

The social benefits are maximized when the diffusion lag has some value between zero and that which maximizes the rate of innovation. At this optimum lag, the benefits that are derived from an increase in the rate of innovation resulting from a given increase in the diffusion lag are just offset by the loss to society from the decreased availability of the new product, resulting from the same increase in the diffusion lag. If the diffusion lag is longer than this optimum, the monopolistic practices of the innovator may more than offset the social gains resulting from the innovation.[23/]

The length of the diffusion lag depends in part on the complexity of the innovation, on the effectiveness of barriers to entry, on whether other firms had been working on the development

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23/ C. Warren Nutter, "Monopoly, Bigness, and Progress", Journal of Political Economy, December 1956, pp. 520-27.

of a similar product, and on the accessibility to knowledge about the profitability of the new product. Some firms will typically respond faster than others.[24/] Questions arise concerning the nature of firms responding to the innovation. Do short-line, long-line, or full-line firms respond faster to the innovation?

Firms established in the farm machinery industry, as well as potential entrants, will vary considerably in the speed and ease with which they can add the new product to their catalogues. Barriers to entry into the market for the new implement can arise because of a number of technological and institutional factors. The potential entrant will be affected differently by these barriers according to whether he is already a full-line, long-line, or short-line manufacturer of farm machinery, or an outsider to the farm machinery industry. The presence of barriers to entry increases the essential costs of getting under way, and thus the level of profits that can be earned by manufacturers of a product without attracting further entry. In any given situation, only a finite, and perhaps very small number, of potential entrants will find that it is worthwhile to add the new product to their catalogues.[25/]

Firms already established in the farm machinery industry, and falling towards the full-line end of the spectrum of "in" firms, may find that they are usually less affected by barriers to entry. Analysis of the performance of their product line may provide strong indications of the profitability of the new implement which has been marketed by another firm. Firms with established brand names or dealer organizations may find it easier to market a new addition to their product line.[26/] In the farm machinery industry,

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24/ For a discussion of how variations in characteristics of different firms affect their speed of response to innovations, see Edwin Mansfield, "The Speed of Response of Firms to New Techniques," *Quarterly Journal of Economics*, May 1963, pp. 290-309.

25/ Cf. Joe S. Bain, *Barriers to New Competition*, Cambridge, Mass.: Harvard University Press, 1956, pp. 11-19.

26/ The importance of this point is illustrated by the fact that the brand name "Frigidaire" was applied to electric stoves and the brand name "Hotpoint" to refrigerators. See Harold H. Hines, "Effectiveness of 'Entry' by Already Established Firms", *Quarterly Journal of Economics*, February 1957, p. 136.

retailers still function as independent businesses that usually handle some implements produced by smaller manufacturers. The marketing barrier is likely to be less important in the farm machinery industry than in industries where full-line forcing is an accepted way of life. Even in the farm machinery industry, however, retailers are under pressure to handle the full lines of major producers.

The pool of management talent in a firm -- the so-called management team -- may be another factor favouring entry by firms already producing farm machinery implements.[27/] As the sales of a new implement grow, the established firm may find that it must alter its catalogue of products in order to maintain its position in the industry. The most obvious response is often to add its own version of the new product to its catalogue. During interviews with company representatives, it was usually maintained that the best indication of the value of any innovation was to observe whether the rest of the industry had followed the innovation.

With continued market experience, more and more firms in the group of potential entrants see the new implement as a worthwhile addition to their product lines. The number of firms offering the new product is likely to increase at an increasing rate, producing a "bandwagon effect".[28/] As the invasion continues, the price and profitability of the new product are likely to decline.[29/] Eventually the number of firms producing the new product will stabilize, and the invasion will come to an end.

Maturity and the Open Period

The market for the new implement may be said to reach maturity when it becomes almost saturated. Most farmers who are potential users of the machinery have already made a purchase. Sales are

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27/ *Ibid.*, pp. 135-36.

28/ Edwin Mansfield, "Technical Change and the Rate of Imitation", *Econometrica*, October 1961, pp. 741-66.

29/ Lester G. Telser, "A Mathematical Note on Entry, Exit and Oligopoly", *Econometrica*, April 1965, pp. 425-33.

confined to population growth, the replacement of worn equipment, and supplying the few remaining farmers who have not yet adopted the new product. During this period, competition usually becomes intense. Price-cutting may develop. Competition may develop along the lines of product differentiation where each minor modification of the product receives considerable advertising emphasis. This period is open in the sense that it is open-ended in duration; it is also open in the sense that the market is open to the full brunt of competition.

The maturity stage can persist for a long period of time, or it may be of short duration. In general, it will last until another innovation appears which displaces the earlier innovation. The market for the earlier product then enters into a period of decline.

2. INVENTION

This chapter examines the process of invention which has been responsible for the development of modern farm machinery. Ideally, it would be desirable to set up a production function relating output to the input of resources into inventive activity. The concept of an output of inventions, unfortunately, poses difficult problems for measurement. Patent statistics provide data on only a fraction of inventions. Historically, the proportion and types of inventions that have been patentable have changed. It is difficult to define a meaningful unit of measurement. Two patented inventions may represent quite different quantities of output: one patent may be commercially useless, while another may represent a break-through which revolutionizes a segment of agriculture. This chapter proceeds to examine certain qualitative aspects of inventive activity in farm machinery. The following chapter will analyze quantitatively the allocation of inputs into organized research and development activity.

It is customary to date the development of the farm machinery industry (as opposed to the blacksmith shop) from the invention of the reaper (Cyrus Hall McCormick, 1831) and, perhaps, the steel plow (John Deere, 1837). The evolution of farm machinery, however, antedates these two inventions. This chapter turns to survey briefly selected strands in the history of farm machinery, and then compares the historical pattern with recent developments in the North American industry and, more specifically, in Canada.

Historical Background[1/]

The plow has been in existence for at least 5,000 years.

1/ This brief account is heavily indebted to the following works: G. E. Fussell, The Farmer's Tools, 1500-1900, London: Andrew Melrose, 1952; Percy Wells Bidwell, and John I. Falconer, History of Agriculture in the Northern United States, 1620-1860, Carnegie Institution of Washington, 1952;

(Continued on p. 16)

Early plows were wooden devices that were dragged along the surface and scratched the soil. The inventive process since then has attempted to modify the design of the plow with two aims: improved cultivation practice and more efficient tillage. This process of modification has taken place in a series of small modifications of design, and changes in the materials used. The widespread experience with this simple tool has produced a large variety of different plows. Many different types of plows continue to exist even today.

As early as 1651, we find observations on the multiplicity of different plows already in existence, and complaints about the lack of any principles for designing an efficient plow. For example,

> I wonder, ... that so many excellent *Mechanicks* who have beaten their brains about the perpetual motion and other curiosities, that they might find the best way to ease all Motions, should never so much as honour the *Plough* (which is the most necessary Instrument in the world) by their labour and studies. I suppose all know, that it would be an extraordinary benefit to this *Country*, if that 1 or 2 horses could plough and draw as much as 4 or 6 and further also that there is no small difference in *ploughs* and *waggons*, when there is scarce any sure rule for making them; and every *Country*, yea, almost every County, differs not only in the Ploughs, but even in every part. Some with wheels, some without; some turning the Rest (as they call it) as in Kent, Picardy and Normandy, others not; some having coulters of one fashion, others of another; others as the *Dutch*, having an Iron wheel or circle for that purpose; some having their Shears broad at the point; some not; some being round as in Kent, others flat... some plough with 2 horses onely, as in Norfolk, and beyond the seas... and one onely to hold and to drive, but in Kent I have seen 4, 6, yea even 12 horses and oxen; which variety showeth, that the Husband-man, who is ordinarily ignorant in Mechanicks, is even at his wits end in this Instrument, which he must necessarily use continually. Surely he would deserve well of this *Nation* and be much honoured by all, that would set down exact rules for the making of this most necessary but contemned *Instrument*, and so for every part thereof;

(Continued from p. 15)

Alfred Stefferud, ed. Power to Produce, United States Department of Agriculture Yearbook, Washington, 1960; W. G. Phillips, The Agricultural Implement Industry in Canada, Toronto: University of Toronto Press, 1956.

> for without question there are exact Rules to be laid down for this,...2/

The moldboard plow was developed through a series of minor modifications in design, often these changes were hardly observable. It was only gradually realized that it was desirable for the plow to turn over the soil. The further realization that the plow could pulverize the soil as it turned the soil over, came slowly, and the desirability of doing this was accepted by farmers even more slowly.

By 1795, scientific methods were being applied to the development of new plows. James Small, a ploughwright, published in England his *Essay on the Construction of the Plough.* This was one of the earliest attempts to develop principles for the construction of a plow. Much of the essay dealt with the proper design of the moldboard so that it would turn the soil over. Many earlier plows still had a straight moldboard which, by its length, made the slice, which was balanced on an untouched ridge of earth, to topple over. Small experimented with different curves for the moldboard which would turn the slice over with the least energy required from the draft animals.

At this time, development of the plow necessarily depended on individual efforts as there were no large firms. Development and invention, however, were not confined to farmers and ploughwrights; agriculture enjoyed widespread popularity as a subject for discussion. The enclosure movement in England and the labour shortage in North America, led to widespread experimentation[3/]

The sophistication of inventive activities continued to grow. In 1784, spring dynamometers were used in comparative plow trials in England. In 1810, Amos used dynamometers to measure soil resistance in his plowing experiments (in England), and he was not the first to do this.

2/ Samuel Hartlib, as quoted by Fussell, op. cit., p. 39. Hartlib went on to advocate the invention of a plow that would be driven across the field with sails.

3/ Lady Stewart of Goodtrees, grandmother of the Right Honourable Earl of Buchan, for example, is credited with inventing the Rutherglen plow. In the United States, Daniel Webster designed a new plow, while Thomas Jefferson, in 1798, used mathematical computations to design a moldboard plow.

The material of the plow changed with its design. Strips of iron had been added to reinforce the various wooden parts of the plow. In 1797, Charles Newbold of Burlington, New Jersey, patented a cast-iron plow. This plow had the disadvantage that the whole plow had to be discarded when one part wore out. In 1813, K. B. Chenaworth patented a cast-iron plow with moldboard, share and land-side in separate pieces. Jethro Wood took out patents on further improvements in 1814 and 1819. The 1819 plow was the first commercially successful cast-iron plow in the United States. Twenty-five years elapsed before this plow won general acceptance. There was widespread fear that cast iron poisoned the earth and encouraged weed growth.

In Britain, Robert Ransome patented a successful cast-iron plow with interchangeable parts as early as 1808.[4/] A farmer could replace the worn part in the field. Ransome was an innovating plow manufacturer who, in 1785, had already obtained an important patent covering a method for tempering cast-iron plowshares.

The next major improvement came in 1837 with the invention of a steel plow by John Deere. John Deere was a blacksmith in Illinois. This plow turned the sticky soils of the United States mid-West better than previously existing steel plows. The John Deere plow had a gestation or development period going back several centuries. Progress towards this plow had gone on in small steps consisting of almost imperceptible modifications.

The design of the plow has continued to change. The adoption of mechanical power necessitated a further wave of plow redesigning. Earlier plows had been designed to operate at the speed of a horse walking. Further changes have come about through the invention of the Ferguson system and the mounting of plows on the tractor. Changes in the basic plow have continued to occur in terms of small modifications.

The rotary tiller has emerged since the Second World War as another instrument for preparing the soil. Throughout the nineteenth century, rotary diggers occupied much attention from

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4/ The firm of Ransomes, Sims and Jeffries Limited is still a major manufacturer of farm machinery in the United Kingdom.

inventors. The attractiveness of applying rotary motion to cultivation was obvious to original minds. Both horse-drawn and self-propelled (steam) units were designed. The Bonser and Pettit machine, for example, patented in 1846, was first designed as horse-drawn, and later as a self-propelled machine.

The basic methods of tackling problems associated with soil preparation, however, have changed but little. Problems are solved by seeking new materials or experimenting with slight modifications in plow design. Plow designs continue to be very varied, and it continues to be an implement built by a great number of small independent firms who coexist with the full-line companies.

The proliferation of plow designs does not seem to have diminished considerably from Hartlib's day. Gaps still exist in such basic knowledge as the pulverization and compacting characteristics of different soil types, and the optimum amount of pulverization or tillage. And yet six yoke of oxen no longer draw a single bottom plow across a field!

The problem of planting the seed has been solved during most of man's history by broadcast sowing. There has been heightened interest recently in the use of seed-drills. The improved efficiency of seed-drilling and other techniques is spectacularly illustrated by experiments with tall fescue and ladino clover conducted by the U.S. Department of Agriculture. Band-seeded plots yielded 130 per cent more forage than plots on which the same amounts of seed and fertilizer were broadcast. Forage yields were 29 per cent greater on band-seeded plots where only one-half the seed and one-third the quantity of fertilizer were applied.[5/]

Seed-drills were used at least as early as 2000 B.C. Early seed-drills consisted of a tube mounted on a plow, and required three men. One man walked with the oxen, one handled the plow, and a third walked along, putting seed into the tube which deposited the seed in a continuous stream.

Seed-drills began reappearing in Europe in the sixteenth century. The development of the seed-drill is another story of

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5/ Elmer B. Hudspeth, Jr., Richard F. Dudley, and Henry J. Retzer, "Planting and Fertilizing", in Power to Produce, U.S. Department of Agriculture, Washington, 1960, p. 148.

slow evolutionary change. In 1623, Alexander Hamilton of England patented a seed-drill, although there is no evidence that this device actually worked. Patents began appearing sporadically after 1623 for planting devices including a patent in 1637 for an instrument to plant carrots. A book appeared in 1646 describing a seed barrow not yet in use which had seed and manure drills -- three funnels for seed and two for a dry powdery manure. During this period, many inventions appeared, although few, if any, were put into practice. In 1839, Grounsell patented a drop drill which placed manure and seed at intervals rather than in a continuous stream. Fussell has summarized the invention of the seed-drill as follows: "The story of the seed-drill since its invention or reintroduction into Europe in the sixteenth century is one of gradual perfection of an idea as the resources of modern engineering developed."[6/] Again the period of gestation extended over several centuries.

In North America, in the 1840s, the general practice was to broadcast seed and then harrow it into the ground. Seed-drills began appearing in the mid-1840s and came into general use during the 1850s in the United States. Billing's corn planter and fertilizer could seed six to ten acres a day in 1856.

The Cockshutt Plow Co. participated in this strand of the story of farm machinery by developing the tiller-combine in the 1920s. This implement consisted in essence of a seed box mounted on a one-way disk. Breaking the soil, cultivating and planting the seed could be accomplished in one operation.[7/] A two-way disk with seed box was developed later.

This brief survey of the historical development of farm machinery concludes with the story of the harvester. McCormick's reaper has been popularly held as the fountainhead for the development of the farm machinery industry. And yet a machine for harvesting grain was already in use two thousand years ago. Pliny the Elder has described a reaper he observed in Gallia. The machine was pushed by an ox, and it did not cut the straw, but the straw was pushed through a comb which stripped off the grain.

6/ Fussell, op. cit., p. 114.

7/ The tiller-combine is significant as a Canadian-developed implement used extensively in Canada. A number of full-line companies added this implement to their product line, even though the market was almost limited to Canada.

John Ridley invented a similar machine in Australia in 1844 and credited Pliny's account for his inspiration. The Australian stripper was in general use for several decades.[8/]

McCormick's reaper (1831) represented the development of the first commercially successful reaper that cut the straw. The idea of a reaper had been discussed for several centuries. Joseph Boyce (England) patented a reaper, in 1800, which consisted of scythes projecting from a revolving disk. Prior attempts had been made to develop a similar machine. In 1800, Robert Meares patented a reaper which consisted of a large pair of shears on wheels, and wires or rods to make the grain fall in the desired direction. In 1805, James Plucknett abandoned the use of scythes and shears for a circular steel plate with a sharpened edge. In 1811, Donald Cumming patented a triangular platform with rotating knives, and in 1812, Smith, a farmer, patented a rotating drum with projecting knives. Many other inventions or attempted inventions were not patented or were not successful. Ogle and Brown built a McCormick-type reaper in 1822, but did not patent it. Patrick Bell, a Scotsman, built a mechanically successful reaper in 1828 and harvested seven acres. Two Bell reapers harvested 30 acres in 1829; five Bell reapers, 87 acres in 1830; and seven Bell reapers, 219 acres in 1831. During trials held in the early 1850s, the Bell reaper outperformed the McCormick and Hussey reapers. The Bell reaper was never patented.

Cyrus McCormick was a Virginia farmer when he built his reaper in 1831. His father had made a number of unsuccessful attempts at building an effective reaper. This reaper was again only one development in a long series of attempts to construct an effective reaper. Obed Hussey had patented the first completely successful reaper in 1833. McCormick's reaper was patented in 1834. Subsequent product improvements and skilful marketing led to the dominance of the McCormick reaper. In 1844, 50 reapers were built by McCormick, and in 1851, 1,000 reapers were built.

8/ The Australian combine uses a method of feeding the wheat to the cutter-bar which differs from that found on North American combines. This difference reflects the historical development of combines in Australia.

The improvements made by McCormick included a chain for a raker. The subsequent trend of development was the gradual development of a self-raker.

Many inventors were working on the development of an effective reaper at the time. A large number of reapers or mowers were marketed in the years following the introduction of the McCormick reaper. In the patent suits that followed, the one involving John M. Manny stands out. Manny retained Abraham Lincoln in 1848 for a fee of $500, the largest legal fee ever collected by Lincoln. The defence was successful, and Manny's reaper was held not to be an infringement on the McCormick patent. That part of the gestation period which immediately preceded McCormick's invention in 1831 was longer than a century.

Threshing was the other operation in harvesting. This operation was especially labour-intensive, and barn threshing provided considerable employment during the winter. Two basic activities were involved in threshing. The grain had to be separated from the head (flailing) and then from the chaff (winnowing). In 1732, Michael Menzies built mechanical flails that were driven by water. The problem with this and many other developments centred on the poor durability of the machines. In 1758, Stirling patented the application of the principle of the flax mill to threshing. The grain was rubbed out. Winnowing machines were in general use by the end of the eighteenth century. These consisted of fans to make wind in the barn and were driven by manpower, horsepower, steam or water.

The threshers evolved step by step to combine flailing and winnowing, were made portable and put on wheels, and further improvements were made. Flailing was replaced by the threshing cylinder, and devices were developed to separate the grain from the straw by vibrating. Eventually, farmers began experimenting with possible combinations of the cutting mechanism of a binder and the thresher to form a harvesting combine.

A combine was built and operated successfully at least as early as 1836 in Michigan, before McCormick's reaper had even come into general use. Two problems faced the innovators: the lack of a suitable power source, and storage of grain with a high moisture content. The combine could harvest and thresh up to 25 acres a day. It was used for 10 years, and then shipped to

California where the climate was drier.[9/] California versions of the combine might weigh as much as 15 tons, and often used as many as 40 horses to pull them across the field. Threshing machine manufacturers were among the first to start manufacturing the combine as it became lighter and less expensive. International Harvester introduced its first combine in 1914; Allis-Chalmers and Oliver added combines to their product line through acquisitions of small-line companies. By 1932, all the full-line companies had combines in their product line.

Massey-Harris was consistently in the forefront of the combine development. The first commercially successful combine in Canada was the Massey-Harris No. 5, introduced in 1922. Massey-Harris No. 1 was originally built in 1906, and was sold in export markets starting in 1910. The major development that followed was the introduction of a one-man self-propelled unit, the Massey-Ferguson No. 20.

Development of this machine was approved in 1936, and prototypes were built within eight months. The inspiration came from observations of local experiments in the Argentine with self-propelled combines. Massey-Ferguson No. 21, a lighter machine, followed and set the pace for the industry in North America.

The sketch of the historical pattern of farm machinery is far from complete; the story of tractors, the Ferguson system and many other significant developments have not been included. Even such "recent" machines as potato diggers are fairly old in concept. A patent for a potato digger was granted as early as 1855, and between 1858 and 1876, 38 patents were granted. The above outline, however, illustrates the evolutionary nature of the inventive process, and the long gestation period that has characterized farm machinery inventions in the past. Gestation periods of a century or more have been common with the products of this industry.

Some of the basic inventions in agriculture led to the founding of major farm machinery companies. Thus John Deere formed a company to manufacture a steel plow, and Cyrus McCormick formed a

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9/ Grain moisture content in northern areas was a problem in the early adoption of self-propelled combines. The windrower was reinvented to allow the ripening to occur in the swath before combining.

company (which eventually became International Harvester) to manufacture the reaper.

The history of the American farm machinery industry prior to 1900 may be described quite briefly as one of strong competition through the development of new technology and through the acquisition of patents and patent rights. Not all companies in the United States were aggressively competitive. A fringe group developed, which only manufactured machines under licence. Most of these fringe companies were either absorbed by the more aggressive companies, or they eventually disappeared from the industry.

The early history of the Canadian industry was similar to that of the American "fringe group". Canadian manufacturers relied on American inventions. They manufactured American machines under licence, or else simply copied American machines that were unpatentable in Canada. Canadian law of the day provided that no device could be patented in Canada if it had enjoyed patent protection for more than a year in another country. Most of the patents issued to Canadians during the nineteenth century applied to simple instruments. Between 1826 and 1860, many patents were issued to Canadians for threshing machines, horse rakes, corn shellers, plows and stump extractors. In 1859, the first patent on a Canadian-developed mower-reaper was granted to Samuel Morse. There is no record that this machine was ever produced. John Collins of Guelph, Ontario, patented a mower-reaper in 1864. This machine was manufactured.

The evolutionary process continued in developing a self-binder. The first patent was issued in 1850, and by the mid-1870s, wire and twine binders were in common use. The first patent on a Canadian-developed wire binder was issued in 1880 to the Massey Company. This binder was not produced. In the 1880s, the Harris Company obtained a patent on an open-end binder. This type of binder was important for penetrating the British market, and this was one of the most important Canadian inventions of the period.

Recent Inventive Activity

The historical trend revealed that farm machinery was invented through a gradual process of evolutionary change. Local skills and expertise were acquired through experience in the field.

Attempts to modify or adapt existing equipment resulted in the development of new concepts applied to farm machinery. This section examines the impact of the farm machinery industry on recent pattern of inventive activity.

The first shred of evidence on the nature of recent inventive activity is provided by Schmookler's study of U.S. patents.[10/] A list of important patents on mechanical inventions in agriculture, 1797-1957, was compiled for that study by Allan L. Olson and Irwin Feller. This list was compiled by studying each patent granted for agricultural implements other than those applicable to engines. The research singled out 218 patents as being important, only three of these being dated in recent times (1945-57). These three entries consist of continuous-running power take-off for tractors (1946), attributed to the Cockshutt Plow Co. -- a Canadian company; a trailer-type corn sheller permitting the picking and shelling of corn in the field or the shelling of it in the cut (1952), attributed to King and Hamilton Co. -- a small-line producer in the United States; and a process for making glass fibre twine for use on balers and binders (1954), attributed to James Slayter of the United States. All three inventions are of the type that permits the farmer to perform old functions more efficiently. None of these is of the type that would revolutionize farming. The absence of revolutionary inventions in the Olson-Feller list for 1945-57 cannot be explained by failure to patent such inventions. The revolutionary inventions are precisely those inventions which are most likely to be patented. The small number of recent inventions listed may be taken as support for the hypothesis that technological progress in farm mechanization continues to be evolutionary even in recent periods. The bulk of improvements occur in small steps, and the individual steps do not appear as distinct breaks with prior technology.

The nature of recent inventions in farm machinery can be examined by looking at those inventions which are considered important by farm machinery manufacturers. In the research and development questionnaire prepared for this study, manufacturers were asked to list the 10 most important inventions made since 1945. Usable replies were received from 10 firms, and detailed

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10/ Schmookler, *op. cit.*, Appendix D.

results appear in Appendix A. Four firms listed less than 10 inventions, while two firms listed more than 10. A total of 99 answers contained 56 different inventions, of which 37 were mentioned only once and 11 were mentioned twice.

Of the eight inventions mentioned more than twice, one -- the self-propelled combine -- was made prior to 1945, although several full-line companies added this product to their lines only after 1945. The development of the corn combine was mentioned eight times. This invention resulted from the experiments of farmers over a period of 30 years, attempts to market corn combines by small-line producers, and university research. The major producers entered the field in the 1950s. This implement was invented by individual farmers; early development was carried through by small-line producers and university researchers; and full-line firms entered relatively late on the scene. At least one full-line producer continues to maintain considerable expenditure on further development of the corn combine. The research appears to emphasize the relation between the implement and agriculture practice (for example, different spacing of rows).

Three other inventions -- hydraulic transmissions (mentioned seven times), hydraulic implement controls (five times) and hydrostatic steering (three times) -- are related to hydraulics. The work on transmission and steering consisted largely of applying inventions made elsewhere to farm machinery, and the necessary modification of these inventions was usually done by firms who supply components to the farm machinery industry. Inventions of hydraulic controls for implements consisted largely of refinements to the basic Ferguson system.

The most significant break-through in hydraulic control consists of a weight-transfer system on tractors. Both weight-transfer systems -- one-point hitch (Allis-Chalmers) and three-point hitch (Massey-Ferguson) -- were invented and introduced by full-line firms. These innovations represent considerable increases in the utility of tractors, both by increasing traction under certain conditions (and hence the capacity to work a greater number of days and the ability to perform more work on those days) and by improving control over the implement. The weight-transfer hydraulic system is a substitute under certain conditions for four-wheel drive and increased horsepower.

Hay conditioners were mentioned six times. This invention represents the introduction of a novel farm implement of a type not used previously. The first hay conditioner was introduced by the small-line subsidiary of a large firm. It was eventually withdrawn from the market. The hay conditioner was reintroduced successfully a number of years later by New Holland -- a long-line firm. The successful version resulted from industrial research and development.

Self-propelled swathers and windrowers were mentioned four times. This innovation involves the addition of a self-contained power source to a pull-type implement, and making appropriate design and engineering modifications. Short-line firms have participated actively in the development of this implement.

Further refinements on automatic balers were mentioned by three respondents. The modern baler was invented around 1939 by a farmer in the New Holland, Pennsylvania area. He brought his invention to the New Holland company, which at that time was a manufacturer of small motors, and did custom foundry work. This invention was responsible for entry by New Holland into the farm machinery industry.

Other inventions were mentioned only once or twice. Most replies showed a bias for inventions made by, or adopted by, the respondent. This type of bias might explain why some of the most recent inventions were mentioned infrequently.

The large number of inventions mentioned only once illustrates that there are few obviously important inventions.[11/] Those that are mentioned often reveal only one really new implement (the hay conditioner), and the others consist essentially of development and application of hydraulics technology, the addition of a power source to a swather, the refinement of balers, and the finally successful development of a way to combine corn. The recent inventions in general follow the pattern of earlier inventions -- evolutionary rather than revolutionary progress.

11/ The small size of the sample and the limiting of replies to 10 inventions may have biased the results towards a wide scatter of replies. A larger sample without restricting the number of inventions, would have eliminated this possible bias. Against this is the fact, however, that many respondents limited their list to fewer than 10 -- seven or less -- inventions.

Is there something in the nature of industrial inventing which creates a bias in favour of evolutionary rather than revolutionary changes?

In examining this question, Hamberg has grouped the relevant factors into three categories:[12/] company R&D aims and objectives, sources of ideas for research programs and location of laboratories, and influence of vested positions.

In its 1958 survey on business investment plans, McGraw-Hill asked a question on the expected pay-off period for research and development expenditures. Ninety-one per cent of the reporting firms expected to recover research and development expenditures within five years or less. The emphasis on the short pay-off period does not, of course, preclude some support of, or for, long-term projects.

In addition to the short time-horizon of financial managers, long-run research designed to provide revolutionary departures from current technology may provide a low private pay-off compared with the large social pay-off.[13/] A radically new machine is likely to encounter considerably more sales resistance than a machine that differs from existing machines only in a few characteristics. In addition, a radically new machine often represents little, if any, advantage over older techniques until a number of subsequent improvements have been made. The new process may be of questionable desirability without these improvements. John L. Enos, in studying inventions in petroleum refining, concluded that "there appear to be greater reductions in factor inputs, per unit of output, when a process is improved than when it is supplanted by a better one".[14/] A radically new farm machine may create the potential for subsequent improvements in productivity rather than make such improvements possible immediately. The innovator thus has to market the new machine during a period when his product is not obviously superior to older types of implements.

12/ Hamberg, op. cit., p. 99.

13/ R. R. Nelson, "The Simple Economics of Basic Scientific Research", Journal of Political Economy, 1959, pp. 297-306.

14/ John L. Enos, "Invention and Innovation in the Petroleum Refining Industry", in R. R. Nelson, ed., The Rate and Direction of Inventive Activity: Economic and Social Factors, Princeton: Princeton University Press, 1962, p. 319.

while improvements to the machine are made which would permit him to increase his share of the market, his competitors can develop their own improved versions of the new machine. The incentive to develop radically new machinery may be completely out of line with the social benefits in terms of improved productivity derived from such machinery.

The source of ideas provides an additional bias towards improvements rather than completely new products.[15/] Research units are often attached to production units. New farm machinery typically is developed in a product engineering department attached to a plant. This organization will tend to encourage improvement of existing products. Customers, salesmen and production personnel will tend to be much more aware of problems with existing machinery rather than with radically new ideas for farm machinery.

Daniel Hamberg argues that "the principal reason for decentralizing R&D has been a desire to establish a closer liaison with the operating divisions".[16/] The divisional research unit is likely to be much more interested in the short-term problems facing the operating group and the clients, such as modifications in materials and products.

The final set of economic arguments advanced by Hamberg run in terms of the vested interest of firms to protect the markets of existing product (through improvements) rather than to destroy the market for its catalogue by making its product line obsolete.[17/] In his arguments, however, he does not take into account the effects of competitors' research on the market for the firm's product line. The timing strategies for introducing new products that will make existing lines obsolete has been examined at length by Robert Reichardt.[18/] The failure to introduce new products may

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15/ Cf. C. E. K. Mees, and J. A. Leermakers, The Organization of Industrial Scientific Research, New York: McGraw-Hill, 1950; and also Hamberg, *op. cit.*, pp. 103-5.

16/ Hamberg, *op. cit.*, p. 104.

17/ *Ibid.*, pp. 105-7.

18/ Robert Reichardt, *op. cit.*, pp. 41-84.

lose a market to competitors. In a non-co-operative situation, the firm must weigh the damage factor on existing markets of introducing a new product against the damage factor of successes introduced by competitors.

The above arguments show that there is considerable bias towards evolutionary modifications as opposed to radical changes in farm machinery.

In addition, the very process of organized research emphasizes the application of technology to a situation in a systematic manner. The research lab may have a comparative advantage in the modification or improvement-type development. This bias towards application-of-technology-type refinements is illustrated by a quotation attributed to the research director of a leading technologically oriented corporation: "Practically all who are now Ph.Ds want to be told what to do. They seem to be scared to death to think up problems of their own."[19]

It must be noted that the farm machinery industry in its evolution from the blacksmith shop to the modern industrial structure has retained room for the individualistic inventor. Most firms still count a number of highly competent, individualistic inventors who often are self-made men rather than the products of formal education.

The greatest part of the inventive activity by industrial units is of the same evolutionary type that has characterized farm machinery during the last several centuries. The advent of engineering teams in farm machinery companies has introduced refinements to inventive methods but has left the basic pattern unchanged.

The Individual Inventor

The individual inventor continues to play an important role in the evolution of farm machinery in spite of the advent of industrial R&D labs. Individual farmers built corn combines, balers, and self-propelled combines before these implements were taken up

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19/ William H. Whyte, Jr., The Organization Man, Garden City, N.Y., 1956, p. 215.

by full-line firms. Quite often, recent inventions were available from small-line firms long before they became available from full-line firms. The full-line firms stress the importance of large volumes and dependability, in making decisions about adding new products to their lines. The farmer with his machine shop and the small-line firm play an important role in providing new ideas on farm machinery, and in providing an initial accumulation of experience with new machinery.

During interviews, R&D managers were asked to provide information about important inventions. The sample of such inventions was likely to be heavily biased in favour of inventions made by the company visited. Nine case studies were developed using this technique:

(1) double-swath windrower
(2) rotary mower
(3) corn combine
(4) cell grate for combine
(5) zero tillage corn planter
(6) hydraulic weight-transfer device
(7) power-shift wheel for tractors
(8) hay conditioners
(9) bale throwers.

Four of these inventions were made by individual farmers. In addition to corn combines, which have already been discussed, the double-swath windrower, the zero tillage corn planter, and the bale thrower were all invented by individual farmers. A double-swath windrower picks up a double swath and can deliver through the centre. Farmers often modified their equipment to do this when crops were light. The first swather, designed and engineered to pick up a double swath, was subsequently developed by John Deere at Welland. The zero-tillage corn planter involved a combination of seeding, fertilizing and herbicide application equipment on one chassis. In addition to saving on labour, this technique allowed moisture conservation, which was critical in certain dry areas. Early experiments were carried on by farmers. J. I. Case often assisted farmers in these experiments. Finally, J. I. Case undertook further development of a machine built by a farmer, and marketed the first zero-tillage corn planter. The first bale thrower that worked effectively was built by a farmer, and, after substantial engineering, was introduced by New Holland. The inventor of the rotary mower is unknown. It was first manufactured by many small-line firms. The first full-line firm to enter the market for this implement was John Deere (Canada).

The disker is perhaps the most significant recent innovation in soil preparation in Western Canada. Similar implements have had a long history in Japan. A one-way disk appeared in the southern United States about 1923.[20/] This implement left trash and thus protected the soil surface from wind and water erosion. It was used in Canada as early as 1925. The search for better shallow-tillage implements led to many experiments by farmers in Saskatchewan. Many implements were designed and tested between 1930 and 1945. More minor improvements were made by R. A. Johnson of Beadle, Saskatchewan, in a disker tried on May 1, 1945. On June 11, 1945, five different diskers were tried at Kindersley, Saskatchewan, and all functioned satisfactorily. The implement was available commercially by late 1945. During 1947 and 1948, when the worth of the disker had been demonstrated, some of the larger farm machinery companies added the implement to their product lines. The entire development process was carried out by farmers in co-operation with university researchers. The swather has a similar history of development by farmers.

The evidence presented on the important role of farmer-inventors is further corroborated in a letter from the Western Development Museum to the Royal Commission on Farm Machinery dated August 26, 1968.[21/] He lists 13 inventions made by farmers, many of them still manufactured by small firms that have become important manufacturers of one or more specialized items.

Interviews with R&D managers in the farm machinery industry revealed that all but one felt that suggestions from farmers were an important source of new inventions. Only one manager suggested that farmers did not think scientifically. The situation contrasts sharply with the automotive industry where managers do not rely on suggestions as an important source of inventions. It might be

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20/ Appendix C reproduces the history of the disker and swather as developed for the Royal Commission by Mrs. A. Doerr, with comments by H. A. Lewis.

21/ Letter from Robert W. UnRuh to Mrs. A. Doerr.

noted, however, that even in the automotive industry, individual inventors have been responsible for two important recent inventions: automatic transmissions, and power steering.[22/]

The development of R&D labs in the farm machinery industry has not yet brought about the invention of a new system for inventing farm machinery. There seems to be at least two important barriers in the way of inventing a more "scientific" system of inventing: first, there is the low scale of production for most implements and hence the high per-unit cost; and secondly, a product line produced by a new system might not perform as effectively initially as products engineered in the present system -- a new pool of know-how would have to be developed which would have to outweigh the pool of existing skills and know-how.

The Invasion

Market share data were available for four products. These data were analyzed to determine the effects of the invasion into the market on the shares of early manufacturers. Rules of confidentiality do not permit the firms or the products to be identified.

The stability of leadership in the markets is very apparent. For two products, the innovating firms led in all reported years. One firm led in eight of ten years for one of the other products, while another firm led in seven of eight years for the remaining product.

Market shares among the three leading full-line firms were examined. These shares varied erratically for one product, but remained fairly stable for the other three products. In two of these three products, the last entrant of the "big three"[23/] managed to rise from third to second position among these three firms.

In the markets for two of the products, full-line and long-line firms who entered early were not able to maintain their market shares. Cases of late entrants who can improve their market position also exist. It appears that the early entrant who maintains

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22/ Jewkes, Sawers, and Stillerman, op. cit., pp. 263-66 and 342-45.

23/ The "big three" are Massey-Ferguson, John Deere and International Harvester.

an alert and aggressive posture will usually also maintain a substantial share of the market. The late entrant, on the other hand, must try harder in order to penetrate the market. One is reminded of a passage from *Alice Through the Looking Glass:*

> "A slow sort of country!" said the Queen, "Now, *here*, you see, it takes all the running you can do, to keep in the same place. If you want to get somewhere else, you must run at least twice as fast as that!"

3. RESEARCH AND DEVELOPMENT

An attempt was made to measure the amount of resources allocated to research and development activities related to farm machinery and performed in Canada. Questionnaires were sent to all the major manufacturers with facilities in Canada, a small number of small-line firms, and all universities in Canada with agricultural faculties. All the major producers and all Canadian universities replied to the questionnaire. In addition, an attempt was made to measure research and development related to farm machinery and performed in the United States by firms with substantial export sales in Canada. Responses varied from complete co-operation to a refusal to provide any information. The poor rate of response coupled with conceptual problems involved in measuring the Canadian relevance of research and development performed in the United States did not permit use of these replies.

The Concept of Research and Development

The standard practice proposed by Organization for Economic Co-operation and Development (OECD) was followed in the preparation of the questionnaire.[1/] Research and development is defined as consisting of three different types of activities:

Fundamental Research

> Work undertaken primarily for the advancement of scientific knowledge, without a specific application in view.

Applied Research

> The same, but with a specific practical aim in view.

Development

> The use of the results of fundamental and applied research directed to the introduction of useful materials, devices, products, systems, and processes, or the improvement of existing ones.[2/]

1/ OECD, Proposed Standard Practice for Surveys of Research and Development, 3rd revision published as No. DAS/PD/62.47 by the OECD.

2/ Ibid., p. 12.

Research and development thus includes both more and less than the total of inventive activity on farm machinery. Research includes attempts to obtain knowledge which is a pre-condition for some inventions but is not itself an invention. On the other hand, many inventions are made by farmers who tinker in their machine shops, and such inventing is not included under our definition.

Much of the research related to farm machinery -- both fundamental and applied -- is performed for other industries, and it is eventually used in the farm machinery industry. Outstanding examples include the technology of hydraulic controls, the creation of methods of inventing (such as the use of stress-coat and dynamometer analysis), and developments in materials (such as new plastics and metallurgy). We might say that the farm machinery industry enjoys a research deficit -- importing more scientific know-how than it exports to other industries. The measure of research and development merely attempts to pick up those activities which were undertaken in relation to farm machinery. In other words, it is an attempt to measure the resources allocated specifically for the improvement or invention of farm machinery.

The exclusion of the inventive activities of the individual inventor is again consistent with the above approach. The farmer tinkering in his machine shop involves little opportunity cost, in the sense of resources that have been shifted from alternative economic uses to research and development on farm machinery. The aim is to measure the magnitude of resources allocated to research and development on farm machinery, and not to quantify the total of "inventive activity", whatever that means.

A number of related activities are excluded by convention. These excluded activities comprise in part the preparation, dissemination and communication of scientific knowledge, other than the library services of a research and development unit; training and education of all types except "on-the-job" training; and the establishment of standards, quality control and similar activities. The research and development unit may also perform other work such as preparation of patent applications, technical services to customers, trouble-shooting, and the like. These technical activities are excluded from the measure of research and development.

The collection of data on research and development involves reliance on many value judgments by the respondents. For example, when does development end and production start? The design construction and testing of prototypes is included as part of research and development whether or not the prototypes are eventually sold. But if adjustments continue to be made after production is started, how is a cut-off determined between the two types of activity? The (U.S.) National Science Foundation uses the following criterion:

> 'If the primary objective is to make further improvements on the product or process, then the work comes within the definition of research-development. If, on the other hand, the product or process is substantially 'set,' and the primary objective is to develop markets or to do pre-production planning, or to get the production process going smoothly, then the work is no longer research-development.' 3/

Measuring Manpower

The two principal ways of measuring input into research and development are in terms of manpower or in terms of monetary expenditure. Use of the manpower approach poses a number of problems. Certain scientists and related personnel may spend only a part of their research time on research and development. The remainder of their time may be spent on problems of production engineering, servicing customers, teaching at universities, and performing various other functions. It is therefore necessary to measure the effort in terms of full-time equivalents. A considerable degree of arbitrariness must be used in estimating the full-time equivalent. In addition, it is extremely difficult, if not impossible, to insure that all response estimate full-time equivalents on a consistent basis. In these procedures, established standard practice is followed.

The measure of research and development thus obtained does not measure the amount of creative effort, but rather the resources which are allocated to research and development. A man-year by any and every engineer would be treated as equivalent to a year spent by Thomas Alva Edison or Harry Ferguson. In addition, no

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3/ National Science Foundation, Methodology of Statistics on Research and Development, Washington: U.S. Government Printing Office, 1958, p. 126.

attempt is made to differentiate between the creativity of five men on one-fifth time each and one man on full-time.

Manpower is usually subdivided into a number of categories:

(1) Qualified scientists, engineers, or their equivalent.

(2) Technicians.

(3) Other supporting personnel.

The first category -- qualified scientists and engineers or their equivalent -- is the most important input into research and development.

Measuring Expenditure

An attempt was made to measure both current and capital expenditure on research and development. These measures were prepared on the basis of cash outlays, thus excluding imputed provisions for depreciation and the like. The expenses included the wages and salaries of research and development personnel including all "fringe benefits"; materials and equipment including libraries and acquisitions for libraries; the costs of prototypes; light, water and fuel; maintenance on research and development facilities; as well as administrative expenses and a share of overhead where research facilities are shared with other departments. In the farm machinery industry, research facilities were usually attached to a producing plant.

Industrial Research and Development

All the long-line and full-line companies with facilities in Canada co-operated by providing data on their expenditures for farm machinery research and development in Canada. Many of these firms experienced considerable difficulty, however, in providing detailed breakdowns of these expenditures by product groups. A number of small-line firms also responded to the questionnaire.

The farm machinery industry has had organized research and development facilities in Canada for over 60 years. The performance of the farm machinery industry in this respect is quite remarkable considering the relatively recent dates when most other Canadian industries have established Permanent Canadian Research and Development facilities. The International Harvester Company of Canada established the Hamilton Engineering Department in 1906, but carried on some research and development activity in Canada before the engineering department was formally set up. Other Canadian firms, including the Massey and Harris companies, also performed research and development in Canada before 1906. Massey-Harris set up a permanent research and development unit in 1918. John Deere organized an Experimental Engineering Department at their Welland Works around 1948. This unit was reorganized as the Project Engineering Department in 1954. The existing Research and Development unit at Cockshutt is dated in 1962, when this company was acquired by White Motors. Prior to 1962, a substantial department existed which designed a long line of implements, and was responsible for a number of basic inventions, including continuous power take-off on tractors. The Canadian farm machinery industry thus has four permanent R&D units. In addition, Allis-Chalmers maintains an R&D unit in Canada dealing with problems other than those related to farm machinery. A number of short-line companies perform R&D on farm machinery without having formal units organized.

Almost all the current expenditures on R&D have been devoted to development rather than to research. Almost all Canadian firms are doing some applied research; John Deere (U.S.) appears to be the only firm in the industry substantially involved in basic research.

The questionnaires asked companies to provide data in current dollars on current expenditures for farm machinery R&D. The data, summarized in Table 1, reveals that expenditures in Canada have increased substantially since 1950. Research intensity was measured by taking R&D expenditures as a percentage of the net value of shipments. Data on the value of shipments were available only since 1960. The level of research intensity reached a peak in 1962, and has declined steadily since then. The Canadian farm machinery industry was less research-intensive in 1966 than in 1962.

Exact figures are not available to measure research intensity for the United States industry. Interviews indicated that a popular rule-of-thumb in the industry was to budget about 4 per cent of the value of sales or shipments. The range in research-

TABLE 1

CURRENT EXPENDITURE BY INDUSTRY ON FARM MACHINERY R&D IN CANADA1/ IN DOLLARS AND AS A PERCENTAGE OF NET VALUE OF SHIPMENTS

Year	Thousands of Dollars	R&D as % of Net Value of Total Shipments by Industry	R&D by Four Largest Firms as % of Net Value of Shipments by These Firms
1950	517 2/ 3/	n.a.	n.a.
1955	1,632 2/ 3/	n.a.	n.a.
1960	3,005 2/	1.7 2/	2.4 4/
1961	2,843 2/	1.9 2/	2.6 4/
1962	3,202	2.0	2.8 4/
1963	3,457	1.7	2.2
1964	4,057	1.6	2.2
1965	4,285	1.5	2.1
1966	4,702	1.4	2.0

1/ Data are based on R&D questionnaires. Data for two full-line firms were provided as a total for farm machinery and light industrial equipment, and the portion allocated to farm machinery was calculated on the percentage of professional R&D personnel employed in farm machinery R&D. Data for a third full-line company include light industrial equipment R&D, which is likely to be negligible in the Canadian figures (less than 10 per cent in the peak year). Net value of shipments figures are those calculated by the staff of the Royal Commission on Farm Machinery.

2/ No data are available for Cockshutt for years prior to 1962.

3/ Figures for 1950 and 1955 contain an estimate for Massey-Ferguson based on a fairly tenuous assumption that the relation of Massey-Ferguson to the total has remained constant. This estimate may be quite a poor approximation, but some estimate is needed because of the importance of Massey-Ferguson in the Canadian industry.

4/ Data are available for only three of the four largest firms.

intensity figures was 1.2 to 3.5 per cent. No Canadian firm reached the 4 per cent figure in any year. There was a remarkable consistency between the size of the Canadian firm and the firm's research intensity. The largest Canadian firm had the highest research intensity in Canada in each of the seven years. The second largest firm in terms of value of shipments was also second in research intensity in six out of seven years. The third largest firm in terms of value of shipments was also third in research intensity in six out of seven years. The fourth largest firm was consistently fourth in terms of research intensity. The consistency of the ranking between net value of shipments from Canadian plants and research intensity in Canada is especially surprising when we realize that the three largest firms -- Massey-Ferguson, Deere and Company, and International Harvester -- are almost equal to each other in terms of worldwide sales.[4/]

A detailed breakdown of manpower figures for R&D in Canada was provided by Golden Arrow, Cockshutt, International Harvester and John Deere. Massey-Ferguson provided total figures for R&D manpower but did not provide a detailed breakdown. Total figures for Massey-Ferguson were allocated to the detailed categories on the basis of the breakdown for the rest of the industry. Figures in Table 2 include all firms that reported farm machinery R&D in Canada. The method for allocating Massey-Ferguson personnel may contain a bias in that it does not reflect the effects of scale of R&D operations on the structure of R&D personnel. In addition, the companies vary considerably in the ratios of supporting personnel to professional personnel, and an error term is introduced. The figures for total R&D personnel should be accurate.

The number of supporting personnel per R&D scientist usually increases with the size of the firm. Data on supporting personnel and R&D personnel are available for all Canadian companies except Massey-Ferguson. The ranking of these companies by net value of shipments and the net ranking of companies by supporting personnel per R&D scientist coincide exactly for all years except 1963. Cockshutt is out of place in 1963, but the R&D facilities for the

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4/ This conclusion is implied in Harvard Business School, Farm Machinery Industry Note (1966), mimeo, pp. A1-232-233.

TABLE 2

NUMBER OF PERSONNEL ENGAGED IN RESEARCH AND DEVELOPMENT IN CANADIAN INDUSTRY, SELECTED YEARS, 1950-66

	1950 4/	1955 4/	1960 4/	1961 4/	1962	1963	1964	1965	1966
					(man-years)				
Professional personnel 1/ 2/	16.0 3/	32.0 3/	32.0	36.0	35.0	39.0	41.5	38.5	39.0
Professional R&D administrators 1/	6.5 3/	8.5 3/	7.5	7.5	12.5	13.5	12.5	12.5	12.5
Total professional personnel 1/	22.5 3/	40.5 3/	39.5	43.5	47.5	52.5	54.0	51.0	51.5
Supporting personnel 1/	n.a.	n.a.	218.0	326.0	335.0	371.0	373.0	392.0	394.0
Total R&D personnel	n.a.	n.a.	357.5	369.5	382.5	423.5	427.0	443.0	445.5

1/ Detailed breakdowns were available from all firms except Massey-Ferguson. The total R&D figures are calculated from replies, and then allocated to different categories according to the total ratio for the industry excluding Massey-Ferguson.

2/ Most of the professional personnel are engineers with a bachelor's degree or the equivalent. Less than three companies replied they had engineers with master's degrees or agricultural scientists.

3/ Figures for 1955 and 1950 are estimated on the basis of trend for those firms who replied.

4/ Figures for 1950, 1955, 1960 and 1961 do not include data for Cockshutt.

Source: Data provided in replies to the R&D questionnaire.

new Cockshutt company were just being set up. The usual pattern in R&D is verified by the data on the Canadian farm machinery industry. Because Massey-Ferguson has the largest R&D program, the method for estimating professional personnel for Massey-Ferguson probably overstates actual professional personnel by one or two man-years.

Great caution must be exercised in interpreting these figures. A recent study in the United States,[5/] for example, listed the farm machinery industry as a technologically intensive industry. It was considered to be similar to aerospace. Technological intensity was measured by taking a ratio of R&D personnel to total personnel. Industries were then ranked according to the value of this measure. The farm machinery industry appeared as technologically intensive because of the large number of products produced with relatively small production runs. Many different models of tractors, combines and other implements have to be engineered. An assembly line may, however, turn out, on any given day, at least one of each of the many models manufactured by the company. The small production runs account for the surprising results obtained by Vernon and Gruber. On the other hand, some other measure, such as R&D personnel per product, would produce an entirely different result.

The quality of technological activity may be indicated partially by an examination of the qualifications of the researchers. No firm replied that it had a doctorate in engineering. Replies on engineers with master's degrees were too few to be reported (less than three firms). Agricultural scientists were reported irregularly. In 1966, the Canadian industry did not employ a single engineer with a master's or doctorate degree. A sample of three responses from U.S. manufacturers revealed 151 engineers with bachelor's degrees, 23 with master's degrees and 3 with doctorates. The Canadian farm machinery R&D effort appears to be technologically less sophisticated than the U.S. effort when this rather simple test is applied.

5/ William H. Gruber and Raymond Vernon, "The R&D Factor in a World Trade Matrix", preliminary paper, Universities-National Bureau Committee for Economic Research, mimeographed, New York, 1968.

Most of the R&D expenditures by the Canadian industry have been directed to combines (see Table 3). Combines and other harvesting equipment account for between 64 and 68 per cent of total R&D by the Canadian industry. Most of the R&D on "other harvesting machinery" is related to the harvesting of grain crops, involving such implements as windrowers.

TABLE 3

R&D EXPENDITURES BY THE FARM MACHINERY INDUSTRY IN CANADA BY PRODUCT GROUPS AS PERCENTAGES OF TOTAL INDUSTRY R&D, 1963-66

Type of Machinery	1963	1964	1965	1966
		(Percentages)		
Combines	35.1	38.7	39.0	38.0
Other harvesting equipment	29.5	25.6	29.8	27.6
Total combines, and other harvesting	64.6	64.3	68.8	65.6
Simple tillage machinery	14.8	13.2	8.1	12.4
Other machinery	20.6	22.5	23.1	22.0
Total R&D	100.0	100.0	100.0	100.0

Source: Calculated from replies to the R&D questionnaires covering about half of the Canadian farm machinery industry.

The Canadian farm machinery industry thus specializes in its R&D in those products which are most important to the Canadian industry in terms of shipments to the domestic and export markets.

University Research and Development

A questionnaire on farm machinery R&D was sent to all Canadian universities with Schools of Agriculture. Usable replies were received from eight universities.[6/] These replies provide the

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6/ The replying universities are: the University of Alberta (Edmonton), the University of Guelph, Université Laval, the University of Manitoba, Macdonald College (McGill University), the Nova Scotia Agricultural College, the University of Saskatchewan (Saskatoon), and the University of British Columbia.

basic data for the analysis of this chapter. Data were requested for the academic years 1949-50, 1954-55, and annually from 1959-60 to 1965-66. Scientific R&D activities in the university sector are divided into two categories: (1) separately budgeted R&D, which includes those expenditures that are supported by separate budgets; (2) departmental R&D, which consists of that portion of the budget item "instruction and departmental research" which was used to support R&D activities.

The total expenditure on separately budgeted research projects exceeded $10,000 in only two years, 1959-60 and 1965-66 (see Table 4). The increase in separately budgeted expenditures in the last year surveyed (1965-66) can be explained largely by the appearance of Canada Department of Agriculture grants-in-aid which appeared for the first time and amounted to $10,800. A grand total of 16 projects were reported, consisting of mechanical methods for drying and conditioning forage crops, grain drying or measuring the moisture content of grain, measuring the moisture content of soils, seed cleaning, grain loss from harvesting equipment, and soil improvement in the Abitibi region through mechanical methods. The total effort seems to be quite modest.

Additional funds are budgeted for farm machinery R&D without being earmarked for specific projects. These funds fluctuated erratically (see Table 4), never exceeding $12,000 until 1965-66 when these expenditures reached $71,100. The change does not represent a dramatic widespread increase in farm machinery R&D. The University of Saskatchewan reported funds budgeted to this category for the first time in 1965-66, and these funds totalled $50,000. They were used to add two research officers and laboratory assistants on full-time research duties to the agricultural engineering department.

Current expenditure figures were deflated in Table 5 to provide a real measure of changes in R&D. A special price index was constructed, based on changes in "instruction and departmental research" per member of faculty at a leading university with a large agricultural engineering department. The magnitude of current R&D expenditures remained remarkably stable between 1954-55 and 1965-66. Most of the increase in 1965-66 reflects the $50,000 increase at the University of Saskatchewan, discussed above.

TABLE 4

CURRENT EXPENDITURES ON FARM MACHINERY R&D AT CANADIAN UNIVERSITIES SELECTED YEARS, 1949-66

(Thousands of dollars)

Year	Budgeted R&D			Departmental R&D			Total R&D on Farm Machinery
	Separately Budgeted Projects	Other Budgeted R&D	Total	Estimated Portion of Departmental Expenses	Material and Other Costs	Total	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1949-50		3.2	3.2	11.9	4.4	16.3	19.5
1954-55		8.5	8.5	34.4	7.6	42.0	50.5
1959-60	10.6	6.2	16.8	49.2	17.8	67.0	83.8
1960-61	6.9	7.2	14.2	56.8	14.3	71.1	85.3
1961-62	7.7	11.7	19.4	66.7	15.7	82.4	101.8
1962-63	3.7	6.0	9.7	73.2	18.4	91.6	101.3
1963-64	7.9	7.9	15.8	87.0	24.3	111.3	127.1
1964-65	7.0	4.5	11.5	94.5	22.2	116.7	128.2
1965-66	24.5	71.1	95.6	104.6	24.6	129.2	224.8

Source: Questionnaire sent to universities.

TABLE 5

CURRENT EXPENDITURES ON FARM MACHINERY R&D AT CANADIAN UNIVERSITIES IN CONSTANT DOLLARS, SELECTED YEARS

(Thousands of 1965-66 dollars)

Year	Budgeted R&D	Departmental R&D	Total R&D
1949-50	10.0	51.0	61.0
1954-55	17.9	89.0	106.9
1959-60	21.3	85.1	106.4
1960-61	17.2	86.0	103.2
1961-62	21.3	89.7	111.0
1962-63	11.1	104.4	115.5
1963-64	17.1	120.2	137.3
1964-65	12.4	126.0	138.4
1965-66	95.6	129.2	224.8

Source: Table 1, and Index of Current Expenditures per Man in Canadian Departments of Agricultural Engineering, calculated from responses to questionnaire.

The effort at Canadian universities may be compared with efforts at U.S. universities. The comparable institutions are the State Agricultural Experiment Stations (SAES). There are 53 SAES, of which 52 are attached to land grant colleges and state universities. The primary mission of the SAES is to work on local agricultural problems -- although the results of this R&D often have far-reaching implications. Non-SAES research is almost completely limited to work in the biological and botanical sciences.

A comprehensive study of agricultural research was undertaken in 1965 by the Association of State Universities and Land Grant Colleges and the U.S. Department of Agriculture. The findings were published by the Association in October 1966, under the title *A National Program of Research for Agriculture*. This study subdivided research activities into 29 categories of which activity 12 -- "mechanization and improvement of physical efficiency" -- comes closest to R&D on farm machinery. R&D on mechanical means for applying insecticides and weed killers is actually included under other categories, and to this extent activity 12 understates the activities we want included. The management of resources and other questions of efficiency are not included in activity 12.

In 1965, the SAES spent $4,571,000 on R&D related to physical efficiency. This figure may be compared with an expenditure of $95,600 by Canadian universities. The Canadian R&D figure is 2.1 per cent of the U.S. figure, but the National program calls for real R&D on the mechanization of fruit and vegetables to more than double by 1972, and for real R&D on the mechanization of field crops to continue unchanged. The total R&D at SAES by field of science was 8.1 million dollars for engineering in 1965-66, although much of this R&D was to support biological research, or research on such problems as structures and drainage.

In 1965, the SAES spent $51,000 for R&D on the mechanization of the cultivation of peanuts, and the U.S. Department of Agriculture spent a similar amount. The U.S. effort on new farm machinery for peanuts (ignoring the industry sector) exceeds the budgeted R&D effort at all Canadian universities for all crops. The total Canadian effort is of the same order of magnitude as SAES activities to improve physical efficiency for the cultivation of ornamental shrubs and turf -- $77,000 in 1965. In problem areas where considerable labour is still required, the SAES effort is impressive. The SAES in 1965 spent considerable sums on the mechanization of deciduous and small fruits and tree nuts ($342,000), vegetables ($479,000), corn ($164,000), cotton ($481,000) and tobacco ($197,000)[7/].

Most of the farm machinery R&D performed by Canadian universities was also financed by these universities. All the departmental research was financed by the universities. Separately budgeted research was financed by the federal and provincial governments, industry and the universities themselves. Industry has financed only one research program, although several firms have co-operated with universities in providing implements to be used in research and teaching. Some funds are also provided in the form of thesis support.

7/ A National Program of Research for Agriculture, Report of a study sponsored jointly by the Association of State Universities and Land Grant Colleges and the U.S. Department of Agriculture (October 1966), Appendix F.

In 1966, the Canada Department of Agriculture (CDA) began implementing recommendations of the National Committee on Agricultural Engineering that increased financing be available for research in the field of agricultural engineering.[8/] Grants of $50,000 were budgeted for 1966, and the amount of these grants was to increase by $25,000 annually until $150,000 was reached.

TABLE 6

BUDGETED FARM MACHINERY R&D AT CANADIAN UNIVERSITIES BY SOURCE OF FUNDS, SELECTED YEARS

(Thousands of dollars)

Year	Federal Government		Provincial Governments	Industry and Other Sources	Total
	CDA	NRC 1/			
1949-50	-	-	1.8	1.4	3.2
1954-55	-	-	5.7	2.8	8.5
1959-60	-	-	16.6	0.2	16.8
1960-61	-	-	14.2	-	14.2
1961-62	-	5.0	13.3	1.1	19.4
1962-63	-	1.0	8.7	-	9.7
1963-64	-	3.0	9.4	3.4	15.8
1964-65	-	4.0	4.5	3.0	11.5
1965-66	20.4	5.0	64.2	6.0	95.6

1/ National Research Council.

Source: Questionnaire sent to universities.

These funds would cover a wide field of research, including farm machinery, irrigation, drainage, equipment testing, crop storage, farm structures, food processing, land clearing, and management engineering studies. Only a fraction of the amount budgeted would be available normally for farm machinery research. In 1965-66, about 40 per cent ($20,400) of the total funds available were granted to projects directly concerned with farm machinery.

8/ Report of the National Committee on Agricultural Engineering, (April 1, 1965), reproduced as Appendix N, Brief to the Royal Commission on Farm Machinery, 1967.

It is doubtful that increased funds to support farm machinery research in universities will encourage a rapid expansion of research unless the relatively high teaching loads in agricultural faculties are reduced. Teaching loads involving six hours of lectures, ten hours of laboratory supervision, and four hours of extension work per week have not been uncommon in the past. Teaching loads involving 14 to 16 classroom hours per week are still common at present. The pattern of teaching loads in recent years shows considerable variation, probably reflecting a process of transition towards lighter loads. A light load might involve five lectures and three or four laboratory hours per week. There has been a widespread reduction in the degree of involvement by faculty with extension work. Not all universities have agricultural engineers specializing on farm machinery.

The universities were asked whether they have a policy of reducing a teaching load in recognition of a commitment to research. Only one university replied that it had such a policy, and one other university stated that it was considering adopting such a policy. The University of Saskatchewan replied that it reduced teaching loads from 9 to 12 hours per week to 4 to 6 hours per week, and in special cases would consider further reductions. The University of Saskatchewan also accounts for the most extensive list of projects among Canadian universities.

The governments seem to perform very little R&D on farm machinery. A survey of agricultural engineering research (1965) conducted by the National Committee on Agricultural Engineering revealed that total R&D in the field of agricultural engineering amounted to 11.45 professional man-years at the Canada Department of Agriculture, and a total of 6.35 professional man-years for all provincial governments. Most of these research projects involved problems not directly related to farm machinery. Only 13 out of 92 R&D projects in agricultural engineering at Canada Department of Agriculture (1967) were related to farm machinery, and only 2 out of 13 similar projects carried out by provincial governments were related to farm machinery.[9/] It is doubtful that total R&D on farm machinery for all governments would amount to more than three or four man-years in 1965. Some of these

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9/ Ibid.

projects involved the design of instruments and implements for specialized experiments with crops rather than attempts to develop new and improved types of equipment for use in production. These figures thus represent a probable serious overestimate of the actual R&D effort.

4. BENEFITS FROM RESEARCH AND DEVELOPMENT

The primary purpose of agricultural R&D is to increase productivity.[1/] The measurement of benefits from agricultural R&D is relatively straightforward compared with problems that arise in attempts to measure benefits from a space program or pollution control program. If resources freed from agriculture do not find alternative employment elsewhere, increased productivity would not necessarily constitute a benefit. This study assumes that resources released by the agricultural sector do succeed in finding alternative employment. Further possibilities exist of realizing additional benefits when resources released from agriculture are more productive in the absorbing industries.[2/] This possibility is ignored in the following analysis. True benefits will in all likelihood be understated for this reason.

Productivity does not tell the whole story of benefits derived from farm machinery R&D. A reduction in the labour force required at critical periods, such as harvesting, may be a way of providing insulation from irregularities in the labour market. Edwin Westcott of Rutgers University emphasized in an interview the high value attached by farmers to the risk that an adequate labour force may not be available at critical periods. Many garden farmers in New Jersey thus "make work", using hand methods rather than the implements they own, hoping that farm workers will stay around until harvest time. Farm machinery can thus provide insurance against the vagaries of the labour market.

1/ Cf. F. M. Scherer, "Government Research and Development Programs", R. Dorfman, editor, Measuring Benefits of Government Investments, Washington: The Brookings Institution, 1965, p. 16.

2/ Ibid., p. 16, footnote 7; also K. Grossfield and J. B. Heath, "The Benefit and Cost of Government Support for Research and Development: A Case Study", Economic Journal, LXXVI, September 1966, p. 543.

The development of improved machinery may also be important in providing insurance against the weather. Many additional benefits exist which are ignored because of the difficulty of measuring them. Improved machinery may reduce the farmer's fatigue or risk of occupational injuries. In addition, R&D expenditures may be an important factor in the development and growth of the farm machinery industry.

Measuring Benefits

The literature on returns to agricultural R&D indicates that the returns are spectacular. Zvi Griliches has estimated that R&D on hybrid corn yielded a return of over 700 per cent per annum.[3/] Most of the R&D expenditure consisted of developmental work to obtain new varieties that are suitable for certain areas. Corn is a major crop. Griliches turned to study the returns on R&D for a minor crop -- hybrid sorghum. He estimated that the rate of return was approximately 400 per cent per annum.[4/] Both estimates were based on total R&D expenditures on both successful and unsuccessful research projects.

The spectacular figures on returns for R&D for hybrid corn and hybrid sorghum represent only two isolated observations. They do not justify conclusions that agricultural R&D as a whole has a high return. Griliches attempted to measure the rate of return on research as a whole. T. W. Schultz estimated that output in 1950 in U.S. agriculture would have required between 3.7 and 18.5 per cent more input using 1940 techniques.[5/] Assuming that this increase in productivity resulted from the total public and private expenditure on agricultural R&D between 1937 and 1951, Griliches calculated that the rate of return was 35 per cent using Schultz's lower bound and 171 per cent using the upper bound.[6/]

3/ Zvi Griliches, "Research Costs and Social Returns: Hybrid Corn and Related Innovations", Journal of Political Economy, October 1958, pp. 414-31.

4/ Ibid., pp. 428-29.

5/ T. W. Schultz, The Economic Organization of Agriculture, New York: McGraw-Hill, 1953, pp. 114-22.

6/ Griliches, op. cit., pp. 427-28.

In later work, Griliches attempted to measure the significance of public expenditure on agricultural research and extension in affecting agricultural productivity.[7/] He used cross-section data for 1949, 1954 and 1959, aggregating some states because of difficulties in obtaining data, obtaining data for 39 "states". He fitted a Cobb-Douglas type production function using per-farm data, including research and expenditure as an input. The variable used for research and extension consisted of the average expenditure per farm by state governments on research and extension. This variable was significant in explaining farm output. In addition, a $1 increase in state research and extension would produce an indicated $13 increase in output.[8/]

Quite often public support for R&D speeds up the appearance of new inventions. The private sector would have produced a similar invention only at a later date. K. Grossfield and J. B. Heath estimated the social returns on a potato harvester developed by the National Institute of Agricultural Engineering.[9/] They estimated that total benefits would equal about three times the costs incurred in developing the NIAE harvester. The implication is that public support for the NIAE harvester was justified even though a number of comparable harvesters were privately developed within a few years.

Wayne Rasmussen has analysed trends in productivity for wheat, corn and cotton in the United States for the period 1800 to 1959 (see Table 7).[10/] He found that man-hours per acre declined almost without interruption for all three crops; yield per acre increased almost continuously; and man-hours per quantity of crop declined therefore even more spectacularly than man-hours per acre. These changes in productivity reflect a

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7/ Zvi Griliches, "Research Expenditures, Education, and the Aggregate Agricultural Production Function", American Economic Review, LIV, December 1964, pp. 961-74.

8/ Ibid., p. 968.

9/ Grossfield and Heath, op. cit.

10/ Wayne D. Rasmussen, "The Impact of Technological Change on American Agriculture", Journal of Economic History, December 1962, pp. 578-91.

TABLE 7

FIELD CROPS: MAN-HOURS PER UNIT OF PRODUCTION AND RELATED FACTORS FOR SELECTED CROPS, UNITED STATES, 1800-1959

Item	About 1800	About 1840	About 1880	About 1900	1910-1914	1920-1924	1930-1934	1940-1944	1950-1954	1955-1959 1/
	Wheat									
Man-hours per acre	56	35	20	15	15	12	9	8	5	4
Yield per acre (bushels)	15	15	13	14	15	14	14	17	17	22
Man-hours per 100 bushels	373	233	152	108	106	90	70	44	27	18
	Corn									
Man-hours per acre	86	69	46	38	35	33	28	25	14	10
Yield per acre (bushels)	25	25	26	26	26	27	22	32	39	47
Man-hours per 100 bushels	344	276	180	147	135	119	127	79	35	22
	Cotton									
Man-hours per acre	185	135	119	112	116	96	97	99	66	66
Yield per acre (pounds)	154	154	196	198	201	155	184	260	296	427
Man-hours per bale	601	439	304	283	276	296	252	182	108	74

1/ Preliminary. Revisions in basic data resulting from 1959 Census of Agriculture not included.

Source: Estimates for 1800-1900 taken from M. R. Cooper, G. T. Barton, and A. P. Brodell, Progress of Farm Mechanization, U.S. Department of Agriculture, Misc. Pub. No. 630, Washington, D.C.: Govt. Printing Office, 1947; 1910-59 data compiled by R. W. Hecht and E. E. Gavett, Farm Economics Division, Economic Research Service, U.S. Department of Agriculture. Reproduced from Table 1, W. D. Rasmussen, "The Impact of Technological Change on American Agriculture", Journal of Economic History, XXII, December 1962, p. 583.

variety of factors -- farm machinery developments as well as the abandonment of less fertile land, improvements in techniques of cultivation, improved varieties of seeds, the development of herbicides and pesticides, to name only a few. Serious difficulties arise if any attempt is made to identify that portion of increased productivity "caused" by farm machinery.

J. F. Furniss of the Canada Department of Agriculture has made a number of studies of productivity trends in Canadian agriculture.[11/] Furniss shows that total inputs in Canadian agriculture remained almost constant between 1935 and 1960, but that agricultural output increased between 1935 and 1965 almost without interruption. He uses a ratio of farm output in index form to an index of production inputs, and finds that his measure of productivity of all inputs rose from 89 in 1935-39 to 165 for 1965.[12/] Labour inputs were declining while inputs of farm machinery and fertilizers were increasing. It is again difficult to infer what portion of this increase in productivity can be attributed to farm machinery R&D. We will develop a model that attempts to measure the effects of farm machinery in the following section.

The Furniss measure of productivity showed an increase during 1946 to 1965 in all regions. The highest annual growth rate was experienced in Quebec -- 3.6 per cent. Ontario followed with a growth rate of 2.9 per cent, and then the Maritimes with 2.6 per cent. Productivity in the Prairies increased at 2.0 per cent per annum, and in British Columbia at only 1.7 per cent. The input of real estate increased in all regions, except the Maritimes. In Quebec, real estate input remained almost constant, while it increased in the other regions.[13/] In the Maritimes, real estate declined at a rate of 1.5 per cent per annum, and labour at 4.2 per cent per annum. Other inputs remained constant; output remained approximately constant; and productivity increased.

11/ J. F. Furniss, "Productivity Trends in Canadian Agriculture, 1935 to 1964", Canadian Farm Economics, April 1966, pp. 18-22; and "Trends in Agricultural Productivity", Canadian Farm Economics, April 1967, pp. 15-21.

12/ Furniss, "Trends in Agricultural Productivity", loc. cit., p.15.

13/ Ibid., pp. 18-19.

Measuring the Benefits from Farm Machinery R&D

The increase in consumers' surplus resulting from improvements in farm machinery can be measured, using a method used by Griliches in his own studies.[14/] If the improved farm machinery had not been developed, costs of producing a given output would have been k per cent higher. Consider the case where supply of agricultural output is completely elastic. In Figure 1, output Q_1 is produced at price P_1. If technological change had not taken place, then production costs would have been greater by some factor k. Less would have been produced, say Q_2, which would have been sold at P_2. k now equals P_1P_2/OP_1. The "loss" of consumer welfare in the absence of technological change would be the shaded area P_1P_2AB. A linear approximation to this area is given by: Loss = kP_1Q_1 $(1 - \frac{1}{2}kn)$, where n is the elasticity of demand.

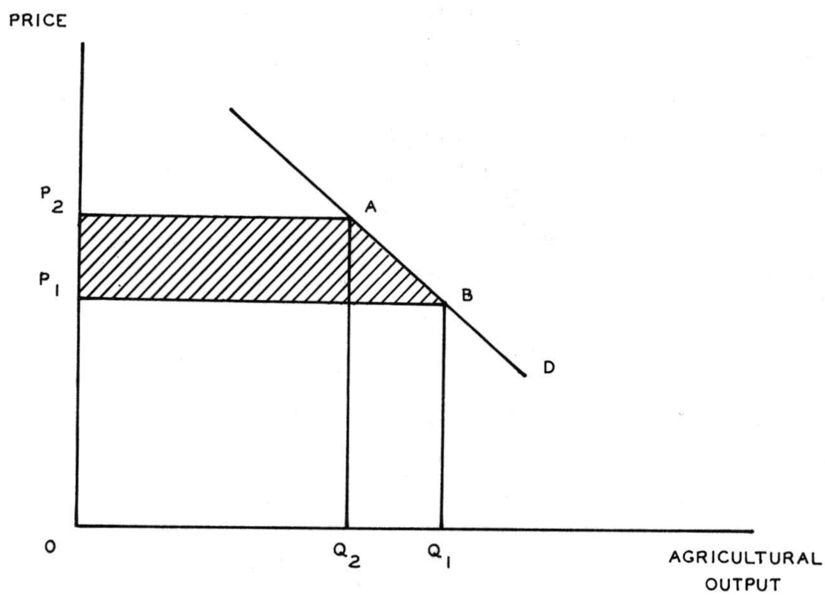

FIGURE 1

14/ See Griliches, "Research Costs and Social Returns", *loc. cit.*, p. 422.

Relaxing the assumption that supply is infinitely elastic would not change the results greatly. Price would change by a smaller amount. New sellers' surplus would be created, some of the old sellers' surplus would be transferred to consumers. The reader can verify that the measure would not be very different from the perfectly elastic case, except when supply is very inelastic.

The use of the formula for a linear approximation provides a convenient computational device for measuring benefits. P_1Q_1 is the value of agricultural output. We have *a priori* expectations about the likely range of values for elasticity of demand, and the formula is not very sensitive to changes in the value of n. k can be estimated from data on agricultural inputs.

Part of the value of k can be measured by studying changes in inputs of labour, machinery, costs of operating machinery, and depreciation on machinery. This measure will miss effects of machinery on improved yields on land. R&D, to improve the control with which fertilizers and herbicides are deposited in relation to the seeds, would, for example, have an impact on productivity as well as on costs. A reduction in the costs of applying fertilizers may also induce more farmers to apply fertilizers, thus increasing the number of operations. Benefits that affect yields will not be picked up by our measure of k.

During the period studied, 1951-66, total acreage in agriculture remained almost constant in Canada. Improved land under crops in Canada was 62.2 million acres in 1951, 62.9 in 1956, 62.4 in 1961, and 69.1 in 1966. Some regions were characterized by farm abandonment, while other regions witnessed an increase in acreage under cultivation. We will simplify the analysis by assuming that real estate input has remained constant. This probably leads to an underestimation of actual benefits.

Changes in hired labour between census years are calculated in Table 8. There was a decrease between 1951 and 1956, 1961 and 1966, but an increase between 1956 and 1961. This increase occurred during a period when improved acres under crops were declining. Other types of agricultural labour, including unpaid family labour, declined sharply between 1956 and 1961. The

TABLE 8

CHANGES IN PAID LABOUR[1/] IN CANADIAN AGRICULTURE
BETWEEN CENSUS YEARS 1951 TO 1966

	1951	1956	1961	1966
Wages paid for labour ($ thousand)	146,080	144,442	194,116	215,691
Wages per month with board 2/	101	115	131	175
Man-months of paid labour in thousands	1,446.3	1,256.0	1,481.8	1,232.5
Change in man-months over preceding census year, in thousands		(190.3) 3/	225.8	(249.3) 3/
Change in paid labour at monthly wages ($ thousand)		(21,887)	29,578	(43,624)

1/ Males over 14 years of age employed for wages in agriculture.

2/ Average wages in mid-August.

3/ Figures in parentheses are decreases in hired labour.

Source: Dominion Bureau of Statistics, Labour Force Survey, Census of Canada, Ottawa: Queen's Printer, various years.

increase in hired labour may represent a substitution of hired labour for unpaid family labour.

For purposes of measuring benefits, changes in paid labour are evaluated at wages with board. As no figure is added in for value of board, and as two of the changes in paid labour involve reductions, this procedure on the whole tends to underestimate the value of reductions in paid labour.

Labour, other than paid labour, fell continuously throughout the period. Calculations for non-paid labour (i.e. "other than paid labour") are presented in Table 9. Reductions in non-paid labour are evaluated at the average realized earnings of "non-paid labour" in Canadian agriculture. Incomes from agriculture of "non-paid labour" may vary considerably from individual to individual. The average figures are biased downward if we consider the alternative earnings to be in manufacturing. Average earnings in manufacturing were significantly higher than those in agriculture. The data do not take into account the part-time employment of some of the agricultural labour outside agriculture. Taking into account the part-time nature of some employment in agriculture, the average earnings figure per man-year of non-paid labour would rise, but the reduction of man-years would fall. The reduction in manpower might rise or fall. It would fall if those leaving agriculture worked a smaller portion of the year in agriculture than those remaining in agriculture. Statistics are not available to test the relative fullness of employment in agriculture of those who left the industry. The downward bias in using the average realized net earnings figure should more than compensate for any error here. In 1956, for example, average earnings for males in manufacturing were approximately double those for "non-paid labour" in agriculture.

The effects on total costs of reduced labour have to be modified to take into account the increased costs of operating machinery. Net benefits are calculated in Table 10. Changes in operating costs covering fuel, lubricants, and repairs are deducted as changes in machinery costs. Changes in depreciation charges are deducted on the assumption that the rate of depreciation is 20 per cent per annum. The results in Table 10 present estimates of the annual flow of cost reductions from farm machinery R&D.

TABLE 9

CHANGES IN NON-PAID LABOUR IN CANADIAN AGRICULTURE BETWEEN CENSUS YEARS 1951 TO 1966 AND RELATED DATA

	1951	1956	1961	1966
Total agricultural labour 1/	892	758	644	493
Less: paid labour 1/	102	96	103	93
Non-paid labour 1/	790	662	541	400
Decrease from previous census date 1/		128	121	141
Realized net income from agriculture 2/		1,238,093	935,288	1,735,278
Realized net income per man-year of non-paid labour		1,870	1,729	4,338
Change in labour evaluated at average earnings for non-hired labour 2/		239,360	209,209	611,658

1/ Figures are in thousands, for males over 14 years of age, as per the June surveys.

2/ Figures in thousands of dollars. Realized net income takes into account supplementary payments and income in kind, but not changes in inventory.

Source: Dominion Bureau of Statistics, Labour Force Survey, Handbook of Agricultural Statistics, Farm Cash Incomes and Quarterly Bulletin of Agricultural Statistics, Ottawa: Queen's Printer, various years.

TABLE 10

COST REDUCTIONS FROM FARM MACHINERY R&D
1951-66

	1951-56	1956-61	1961-66
	(Thousands of dollars)		
Labour saved:			
Paid labour	21,887	(29,578)	43,624
Other labour	239,360	209,209	611,658
Total saving of labour	261,247	179,631	655,282
Less: Increase in machinery costs	65,207	40,807	150,000 1/
Change in depreciation 2/	60,000	70,824	196,800
Net cost reduction from R&D	136,040	68,000	308,482

1/ Estimated.

2/ Change in value of implements and machinery calculated from Census of Canada. Depreciation charge calculated at 20 per cent per annum.

Source: Dominion Bureau of Statistics, Tables XIII-1 and XIII-2, Handbook of Agricultural Statistics, Census of Canada, Ottawa: Queen's Printer, various years.

TABLE 11

CALCULATIONS OF RETURNS TO R&D

	1951-56	1956-61	1961-66
	(Millions of dollars)		
Cost reduction after R&D	138.4	71.8	313.7
Loss of welfare if supply of agricultural goods is infinitely elastic			
When demand elasticity = .5	136.6	71.4	307.3
When demand elasticity = 1.0	134.9	70.9	301.7
R&D expenditure for five-year period	12.6 1/	9.1 1/	26.3

1/ Estimated by interpolating.

Source: Dominion Bureau of Statistics, Table XIII-3, Quarterly Bulletin of Agricultural Statistics, Chapters XII-X. Ottawa: Queen's Printer, various years.

The timing of R&D expenditures does not coincide with the reaping of benefits. R&D creates a new best-practice technique. There may be a considerable time lag before the new best-practice technique comes into general use. The figures in Table 10 indicate the increased cost required to produce the actual outputs of these periods had farmers not adopted some of the newer best-practice techniques. The reader should be cautioned that the difficulties of measuring benefits are sufficiently great, that these figures can only be regarded as a first approximation of the benefits actually realized.

In Table 11, the cost reduction figures are adjusted for the cost of R&D which is included in the cost of farm machinery. The linear approximation of the measure of "loss" of consumer welfare is applied, using two assumptions -- that the elasticity of demand for agricultural goods is .5, and 1.0. The resultant measures of consumer welfare are all close to the raw measure of cost reduction.

Table 11 contains measures of benefits for farm machinery R&D and cost figures for R&D performed in Canada. The cost figures are calculated as totals for five-year periods. The benefits are calculated as per annum flows in perpetuity from new techniques *adopted* (rather than introduced) during the same five-year period. The two figures are presented for comparative purposes. The reader is cautioned that some of these benefits flow from R&D performed in the United States. There is no statistical technique available for imputing a portion of these benefits to Canadian R&D. The average return in terms of Canadian benefits on total North American R&D is still likely to be impressive. For example, if the North American R&D expenditure is 20 times the Canadian expenditure, the return for 1961-66 would still be close to 60 per cent. The reader is also reminded that the calculations of benefits ignore the effects of improved machinery on crop yields, and also ignore the effects of R&D on the development of a Canadian farm machinery industry.

5. CONCLUSIONS

While expenditures on research and development have increased greatly in recent years, the individual inventor on the farm continues to be the most important source of both major and minor inventions in farm machinery. The major machinery manufacturers themselves have confined their R&D expenditures almost exclusively to development rather than research. Research projects on new techniques of grain separation for combines at Massey-Ferguson and at Cockshutt are the only major exceptions to the general pattern in Canada. The basic research projects at Deere & Company in the United States provides another notable exception to the general rule.

New farm machinery designs continue to evolve over the years in much the same pattern that has characterized the development of farm machinery developments in past centuries. Relatively simple new combinations of known implements and known components are made by farmers, and sometimes these are hailed as revolutionary inventions. R&D units of farm machinery manufacturers enter the picture at a relatively late stage of development, providing sophisticated engineering techniques to upgrade the design of the new implement before production begins. R&D units also periodically upgrade the existing product lines of the industry. Expenditures by R&D units aimed at inventing radical departures are relatively scarce. The reluctance of the farm community to accept radical changes involving substantial capital outlays may be an important reason explaining this phenomenon. Jesse Markham found such resistance in the farm community towards radical departures in farming techniques.[1/]

1/ "[The family-farm operator] ... usually did not innovate and frequently was slow to adopt the innovations of others. This is <u>not</u> to say that <u>no</u> family-farm operators innovate. Many do. It does say that most family-farm operators do not ..." Cf. Jesse W. Markham, <u>The Fertilizer Industry</u>, Nashville: Vanderbilt University Press, 1958, p. 19.

The pattern of invention in the farm machinery industry contrasts sharply with that found in the automotive industry, which shares similar production processes and technologies. Differences in production processes as well as in patterns of R&D can be explained substantially by the relatively small size of production runs for any given farm implement. The large number of different versions of each implement that must be produced, and the short production run for any given version, will result in a relatively high ratio of engineering costs to production costs.

While total expenditures on R&D by the Canadian farm machinery industry has grown steadily, the research intensity of this industry (measured as the ratio of R&D expenditures to value-added) has fallen consistently since 1962. The research intensity of the four largest firms in Canada has consistently fallen short of the research intensity indicated for the United States. The lower research intensity of this industry's operations in Canada exists even though this industry has a tradition of decentralized operations. Canadian plants are largely responsible for their own R&D. The product mix of Canadian plants is apparently biased in favor of lines which embody less "technology" than the product mix of U.S. plants.

The four largest firms accounted for almost all R&D expenditures by the industry in Canada. In six out of seven years, the ranking of the four largest firms according to size by value-added coincided with their ranking according to research intensity. This coincidence of the two rankings appeared even though the three largest firms were of close to equal size in terms of world-wide sales. The research intensity of the Canadian operation thus coincided with the size of the Canadian operation.

Governments and universities perform very little R&D on farm machinery in Canada. Although expenditures on agricultural engineering research have increased greatly in recent years, the new levels of expenditure in Canada are scarcely sufficient to provide resources to collect information on technology developed in other countries, and certainly not enough to initiate any major research programs.

In considering public support for R&D on farm machinery, it would be desirable ideally to measure rates of return on such expenditures. Unfortunately, such calculations are impossible. Serious conceptual problems plague attempts to measure yields on past expenditures on R&D in this area. The evidence available in this study, and in other research, indicates that the average yield on R&D expenditures has been large in the past. Even projects that had limited applicability, involving machinery for minor or specialty crops, showed high rates of return.

An increase in R&D expenditures would be consistent with the high returns indicated for this type of investment. Available data indicate that the innovating firm in this industry seems to be able to maintain a substantial position in the market for the new implement even in the long run. The commercially sustainable level of R&D expenditures, however, is likely to fall short of that which is socially optimal. A substantial portion of the benefits appear as reduced costs in agriculture, and are reaped by consumers and food handlers who pay lower prices for foodstuffs. These benefits can seldom be recovered by the farm machinery manufacturer. Individual farmers will almost certainly lack the facilities to undertake scientific R&D activities. The classic conditions for advocating public support -- externalities and the existence of a large number of small users -- are found in the farm machinery industry. Support for R&D would be important not only in maintaining the competitive position of Canadian agriculture, but also in fostering the future development of the Canadian farm machinery industry.

APPENDIX A

IMPORTANT INVENTIONS IN FARM MACHINERY MADE SINCE 1945

The research and development questionnaire contained the following question: "Please list what you consider to be the ten most important inventions in farm machinery since 1945. Note: You may list fewer than ten inventions." Results are presented below in Table A-1. Ten firms provided usable replies, and 56 different inventions were mentioned in 99 answers received. The replies are probably biased in favour of inventions made or adopted by replying companies. In addition, the replies are probably also biased in favour of recent inventions which may be vivid in the respondent's memory.

TABLE A-1

INVENTIONS MADE SINCE 1945 AND MENTIONED BY FIRMS AS IMPORTANT

Invention	No. of Times Mentioned		
Hydraulics			
Hydraulic transmissions		7	
Hydraulic implement control		5	
Hydrostatic steering		3	
Weight transfer		2	
Four-wheel hydraulic drive		1	
		18	
Three-point hitch[1/]		2	20
Combines			
Corn combines and corn heads		8	
Self-propelled combine[2/]		4	
Combine straw chopper		1	
Variable speed belt drive		1	
Auger-type grain header		1	
Rubber-covered cylinder bar		1	16
Hay Conditioners and Balers			
Hay conditioner		6	
Automatic balers	3		
Small baler	1	4	
Hay cuber or waferer		2	
Bale thrower		2	
Combination mower-crimper		1	
Flow action feeder for baler		1	16

TABLE A-1 (*Continued*)

Invention	No. of Times Mentioned	
Self-Propelled Other than Combines		
S-P swathers and windrowers	4	
Variable belt transmission for S-P swathers	2	
S-P cotton picker	1	7
Miscellaneous Inventions Related to Tractors or Combines		
Diesel power adoption	1	
Adjustable rear wheels on tractors	2	
Cabs for drivers	1	
Live power take-off	1	
Dry-type air-cleaners	1	
Locking differential	1	7
Miscellaneous Plowing and Planting Equipment		
Plastic seed plates and knockers	1	
Fiberglass fertilizer hoppers	1	
Grain-drill dump bottom (for fertilizer)	1	
Sprayers for herbicides and insecticides	2	
Liquid manure handling equipment	2	
Dup chisel plow	1	
Harrow bar	1	
No-til planter	1	
Vibrating subsoiler	1	11
Miscellaneous Harvesting Equipment		
Pitmanless mechanical tire	1	
Cotton stripper	2	
Oblique reel raker	2	
Sealed storage	1	
Combined picker-sheller	2	
Double-swath attachment	1	
Double-auger windrower	1	
Side-delivery "Rolabar" rakes	1	
Grain loaders for bulk handling	1	
Balanced knife drive	1	
Direct and row forage harvester	1	
Fruit and vegetable harvesters	1	
Flail-type forage harvester	1	16

TABLE A-1 *(Concluded)*

Invention	No. of Times Mentioned	
Miscellaneous Equipment		
Farmstead mechanization	1	
Forged steel guards	1	
Mechanical unloading	1	
Tires for implements	1	
Anti-friction sealed bearings	1	
Nylon bearings	1	6
Total		99

1/ The standard adoption of a three-point hitch is closely related to hydraulic implement control.

2/ Massey-Harris combines Nos. 20 and 21, both self-propelled, are shown in the book by E. P. Neufeld, A Global Corporation, Toronto: University of Toronto Press, 1969, p. 412 under dates of 1939 and 1940. Therefore, the S-P combine as we know it today was invented before 1945, despite the reference by four companies to it as a post-1945 invention.

APPENDIX B

TRACTOR TECHNICAL DEVELOPMENT

by

Bruce D. Narsted

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LIST OF FIGURES

Summary

The development of tractors started with the recognition of the need for mechanical power greater than that which could be supplied by draught animals. Cyrus McCormick invented his reaper in 1831 and it, along with similar machines, created a demand for belt power with which to thresh mechanically harvested grain crops. Steel plows, mowers, shellers, fodder cutters and other machines that were commercially available after 1860 also created a need for mechanical power. It was the manufacturers of these machines, particularly threshing machines, who undertook the production of moveable steam engines.

The early farm steam engines furnished belt power but had to be pulled from place to place by animals. The first steam traction engine was developed primarily for plowing and was put into operation in 1855. By 1900 more than 30 firms were manufacturing 5,000 large steam traction engines a year. Big wheat farms in the mid-north and western states and Canada provided the major markets. Around 1850, development started on traction devices other than wheels, and the end result was the crawler-type or track-layer tractor. Track-layers continued to be used as alternatives to wheeled tractors on the farm until the late 1950s.

The gasoline engine, developed by Otto in 1876, was finally produced in quantities by 1890, and by 1899 one hundred firms in the United States were manufacturing internal combustion engines. The diesel or compression ignition engine was invented in 1892 by Dr. Rudolph Diesel, but was not used as a tractor power unit until 1931 when Caterpillar introduced it in the United States. The use of diesels in tractors climbed steadily thereafter.

Although gasoline-engine tractors and steam tractors were rivals, it was not until 1908 that the public was able to compare the performance of both these types, when the first Winnipeg tractor trials were held under the auspices of the Winnipeg Industrial Exhibition. In those trials and in tests in 1909-12, representatives of many countries witnessed the competition of gasoline tractors plowing in the same field as steam tractors.

The first Winnipeg trials were mainly contests of hauling and plowing for comparison of such factors as the thousands of foot-pounds hauled per pint of fuel and the pints of fuel used per acre. The trials were continued each year until 1912, and they became more comprehensive so that in 1912 the score sheet included an economy brake test, maximum brake test, plowing test, and a rating on design and construction.

Between 1910 and 1920 the number of tractor manufacturers increased from 15 to more than 160. A trend began towards smaller tractors to satisfy the demand for mechanical power among the smaller grain and livestock farmer. The concept of an all-purpose tractor began to take shape. In 1917 the Ford Motor Company applied the production-line technique, which had been so successful with automobiles, to the tractor, producing the unit-frame Fordson which was light for its power and relatively low in price. The power take-off was also introduced during this decade.

In 1923 Deere & Company offered their rugged Model D tractor. Its great popularity -- which was such that it was not discontinued until just after the Second World War -- was due to its low cost, the fact that it could operate on almost any fuel, ease of repairs, and the fact that the engine was not sensitive to carbon deposits (one of the problems of the times).

During 1928-29 Deere introduced the first mechanical power lift for integrally mounted implements on a tractor -- their GP tricycle tractor. Other refinements around the same time were Oliver's "tiptoe" drive wheels, and Massey-Harris' four-wheel-drive tractor.

In the 1930s, pneumatic tires were introduced, and by 1935 about 14 per cent of all new tractors were on rubber. The proportion rose to 85 per cent by 1940 and 100 per cent by 1950.

The draw-bar power of general-purpose tractors increased at an average annual rate of about three per cent during the 1930s and 1940s. At first this increase was the result of the introduction of pneumatic tires, rather than any increase in engine power. After that, it was due to increased use of "regular" gasoline which had a higher octane rating than the distillate fuels. Other reasons were the increases in cylinder bores and the "aeronautical influence", exemplified by large increases in rated engine speed (from about 1,100 rpm to 2,500 rpm).

Just before, during, and after the Second World War, a great deal of development was done on hydraulic systems for tractors. The "Ferguson System", an ingenious adaptation of hydraulics to the control of mounted tractor implements used with a three-point hitch, was one of the first results. Hydraulics have since been applied to everything from remote control of trailed vehicles to power steering and transmissions.

In 1941 a third major fuel type, besides gasoline and diesel, made its appearance. LPG or liquified petroleum gas must be kept under pressure to keep it liquid, and so it requires a special fuel tank and modified carburetion system. The market for LPG tractors has varied widely over the years, from about four to ten per cent of the total market.

The most significant change in farm tractors to take place in the fifties and sixties has been the rapid increase in tractor power -- the so-called "horsepower explosion". New models with higher horsepower came out so rapidly that it was sometimes hard to tell whether the manufacturers were forcing higher horsepower on their customers or whether the farmers were really demanding high-powered tractors.

Today the major areas of development are new types of transmissions, traction problems (with solutions such as four-wheel-drive), hitching and implement systems, and tractor safety.

Following this summary is a more detailed history of some of the major areas of tractor improvements.

Engines

Obed Hussey of Baltimore invented the first steam traction engine in 1855; it was called the "steam-plow". A more successful one by J. W. Fawkes in 1858 drew eight plows at 3 mph in virgin sod. Others were put on the market in 1868. They ranged between 10 and 60 HP, their operating speed was between 1.7 to 3.4 mph, and their plowing rate was up to five acres an hour -- a level of performance that compares favourably with today's small- and medium-sized tractors.

At the zenith of steam traction engine development, near the turn of the century, they often weighed more than 45,000 pounds and developed more than 120 HP. They were of the horizontal- and vertical-tube boiler type and had an operating steam pressure of 150 to 200 psi. The power train usually consisted of spur gears made of cast iron, with only one or two forward speed ratios. Steering was sometimes aided by engine power.

The steam tractor had disadvantages when used for field work. It was very heavy and slow-moving, and the fuel was bulky and presented "materials handling problems". The job of supplying boiler water and fuel meant constant attention on the part of one man, and a second man was required to handle and guide the tractor.

The discovery of petroleum fuel in 1859 speeded the development of the internal combustion engine. Previous attempts at internal combustion used gunpowder, turpentine, and natural and artificial gas. The most important early contribution to the development of the internal combustion cylinder and piston engine was the statement of the four conditions essential for efficient operation by Beau de Rochas, a French engineer. They are as follows:

(1) the greatest possible cylinder volume with the least possible cooling surface,
(2) the greatest possible piston speed,
(3) the highest possible compression at the beginning of expansion,
(4) the greatest possible expansion.

Although stated in 1862, these are the design goals of every new engine that comes out of Detroit today.

Beau de Rochas later went further and proposed the well-known four-stroke cycle of intake, compression, ignition, and exhaust. He never succeeded in constructing a working engine himself, and it was not until 1876 that Dr. Nicholas Otto patented the first really successful engine using the four-stroke cycle. The cycle promptly became known as the "Otto cycle" for spark-ignition engines. It was unfortunate that Otto's patents were of such a basic nature that other companies were unable to produce similar engines until 1890 when the patents expired. The gasoline engine was applied to the traction engine by John Froelich in 1892, and others soon followed. The two-stroke cycle engine was patented by Dugald Clerk in 1878 but was not fully developed until 1881.

Before 1910 most of the gasoline tractors produced commercially had automatic intake valves, "hit-and-miss" governors, and "make-and-break" ignition systems. Electric current for ignition was usually supplied by dry batteries for starting, and by low-voltage, direct-current magneto or generator (auto sparker) for furnishing current thereafter. In a few tractors, a low-voltage oscillating magneto furnished the spark for starting and running the engine. By 1916 the high-tension magneto ignition with impulse starter had replaced the "make-and-break" and low-tension systems. In 1917 the Model D Moline Universal was the first tractor to be equipped with a storage battery for ignition, starting, and lighting. Magneto systems of ignition were used with little improvement up until the early fifties when they were replaced with ignition systems using storage batteries, generators, and starters. There were mostly 6-volt systems at that time but a general changeover has followed the 12-volt systems.

In 1916 the better fuel systems consisted of a carburetor delivering a mixture of fuel, water, and air (the water was used to control combustion), combined with an intake manifold, intake passages, valve porting, and a combustion chamber designed to produce high turbulance and swirl (which was found to effectively control detonation or knock). Water is no longer used to control combustion, and carburetors are much more complicated today.

Before 1910 most of the tractors had horizontal single- or double-cylinder engines, such as International Harvester's 45 HP "Mogul" with two horizontally opposed cylinders. Many of the smaller tractors of the 1910-20 decade were equipped with two- and even four-cylinder engines. In 1916 Deere & Company brought out the "Waterloo Boy" with a twin horizontal cylinder kerosene-burning engine and a 180-degree crankshaft mounted perpendicular to the axis of the tractor. This basic engine configuration was not changed by Deere until 1960. Other manufacturers tended towards the four-cylinder vertical in-line engine, which is fairly standard on today's gasoline-engined tractors. Recently some six-cylinder engines have appeared in use.

By 1920 most cooling systems were enclosed, and later models were pressurized with water pumps to circulate the coolant. In 1923 Deere & Company used a thermo-siphon cooling system which eliminated water-pump packing problems. This type relies on the convection currents in the coolant for circulation. Today's tractors have abandoned the thermo-siphon type, and have gone back to the pressurized, pump-circulated type with a radiator, fan, and thermostat.

Lubrication before 1920 was of the "splash" type; it relied on the agitation of the oil in the crankcase to splash oil on all the moving parts. The Moline Universal tractor with its new four-cylinder engine, in 1920, was one of the first with a five-bearing crankshaft, with oil under pressure supplied to all journal bearings through drilled passages in the crankshaft. This new engine in the Moline Universal was interesting in that it was "high speed". Its rated engine speed was 1,800 rpm while that of its contemporaries ranged between 800 and 1,000 rpm. Today's engine speeds are around 2,500 rpm for gasoline engines and slightly less for diesel and LPG engines.

Air cleaners, which are of some importance to tractors because of the dusty environment in which they usually work, come in three basic types: dry-type with filter, wet-type oil bath, and the centrifugal type (no longer used). The oil-bath type predominated in the forties and fifties, but the dry-type with a pressed fibre filter now is slowly taking over the market. In 1923 the results of an extensive series of tests on air cleaners by the University of California at Davis showed that although there were many different makes and types on the market, at least half of them were 95 per cent efficient.

The large increases in tractor horsepower over the past 15 years have been due mainly to the increased use of diesel engines. In the words of Dr. MacHardy,[1/] in answer to the question of what he thought was the most important development in farm machinery over the last 20 years:

> . . . in so far as predominantly grain farming is concerned, I think that it has largely been tractor improvements. In 20 years . . . I think we have seen a great increase in the use of diesel fuel and a consequent levelling or favourable price relationship with respect to diesels.

1/ Dr. F. V. MacHardy, Chairman, Department of Agricultural Engineering, University of Alberta, Royal Commission on Farm Machinery Hearings, Vol. 3, p. 300.

W. H. Worthington is not quite so enthusiastic:

> Customer preference for diesel powered tractors in the smaller horsepower ranges is sometimes hard to justify on economics alone. Users like them for reasons of economy, long life, low-speed lugging characteristics, reliability and long life between overhauls. To some extent, they serve as a 'status symbol'. Diesel engines of today are sophisticated in their design and require a high order of skill to repair and overhaul them. Farmers rarely attempt to overhaul them themselves.2/

The increase in the proportion of diesel tractors, and in the average horsepower of tractors sold in Canada, is shown in Figures B.1 and B.2. Taken together with the knowledge that diesel engines are more commonly used in tractors of higher horsepower, it shows the increase in diesel horsepower which has taken place.

The diesel or compression ignition engine was invented in 1892 by Dr. Rudolph Diesel. Diesel's first engine was unsatisfactory and it was not until 1898 that the first successful diesel engines were produced. Unlike the Otto cycle, the Diesel cycle uses the heat of compression of the air to ignite the fuel when it is sprayed into the combustion chamber. This is why diesels have such a high compression ratio compared with spark ignition engines. Diesel fuel continues to burn throughout most of the power stroke, and this is the reason for the diesel's well-known "lugging" ability. Some of the problems that have hampered diesel development have been fuel-injection systems, cylinder cooling, and the meager knowledge of fuel-spray characteristics.

The next major and logical improvement in engines was the addition of a supercharger or turbo-charger to the diesel engine. This device simply blows or packs more air into the cylinders, thus increasing the volumetric efficiency of the engine. It allows a substantial increase in horsepower with a small increase in weight and relatively small increase in cost. As recently as 1966 turbo-chargers had to be installed as field conversions on tractors, but in that year a number of manufacturers introduced tractors with turbo-charged diesel engines -- in particular the 100 HP International Harvester 1256 Turbo, and the International Harvester 4100 at 110 HP. Since then every major tractor manufacturer has introduced turbo-charged diesel engine tractors.

2/ W. H. Worthington, "50 Years of Agricultural Tractor Development", Paper given at Society of Automotive Engineers, Farm, Construction and Industrial Machinery Meeting, Milwaukee, Wisc., Sept. 12-15, 1966.

FIGURE B.1-CANADIAN WHEELED FARM TRACTOR SALES; TOTAL HORSEPOWER; GROWTH OF DIESEL POWER

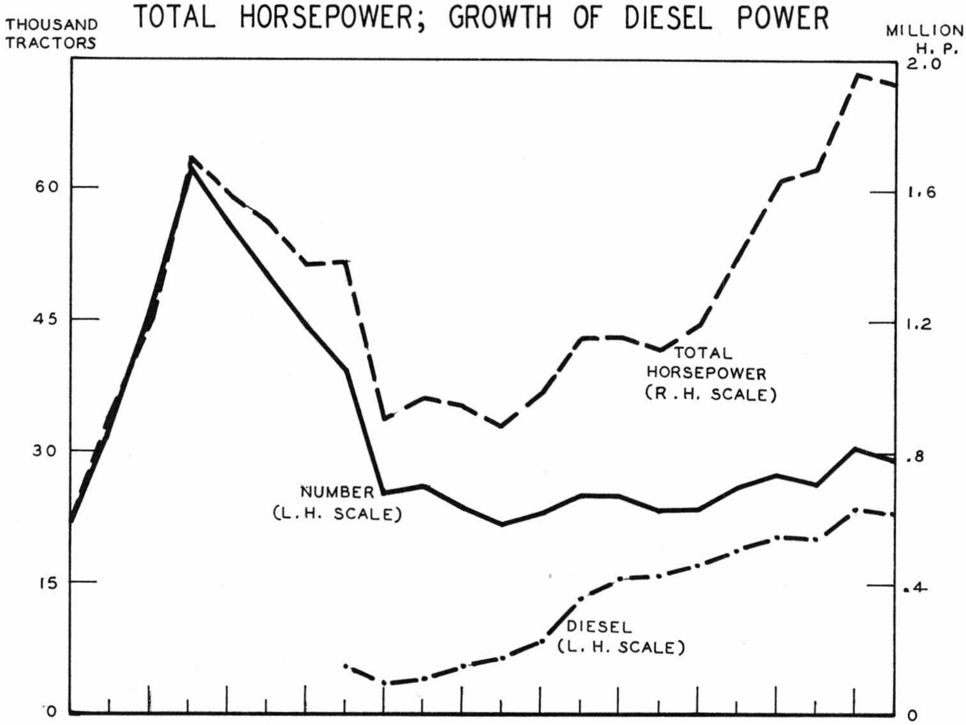
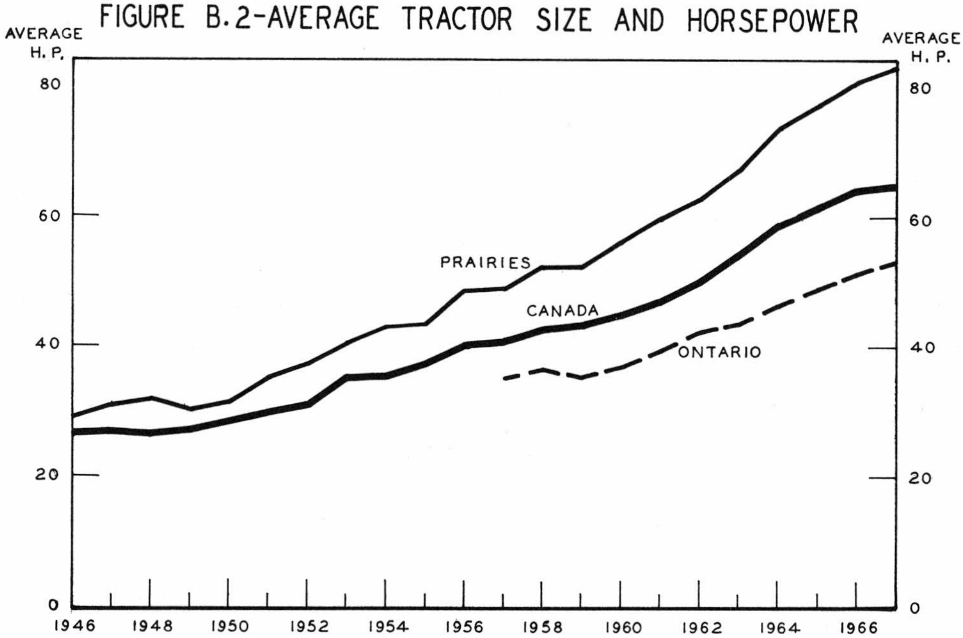


FIGURE B.2-AVERAGE TRACTOR SIZE AND HORSEPOWER



SOURCE: DOMINION BUREAU OF STATISTICS, MERCHANDISING AND SERVICES DIVISION, FARM IMPLEMENTS AND EQUIPMENT SALES, CAT. NO. 63-203 (OTTAWA: QUEEN'S PRINTER, VARIOUS YEARS); HORSEPOWER ESTIMATES (TOTAL AND AVERAGE) DEVELOPED FROM ABOVE.

Besides turbo-charging, there are two other "bolt-on" ways of increasing engine power. LP gas injection is the most recent and is used only on diesel tractor engines. As the engine nears its full power output, a small amount of LP gas is fed into the intake manifold of the engine. The result is a modest power increase, coupled with a "cleaner" exhaust. Its installation is not difficult and it is relatively inexpensive. The other, older method of increasing engine output power is not limited to diesels. The pistons may be exchanged for slightly longer ones, or the cylinder head may be modified. The result in either case is an increase in compression ratio. Higher compression engines "squeeze" the fuel-air mixture tighter before the spark-plug fires. Each fuel charge thus gives more power when it burns.

Power Train and Transmission

One of the earliest important developments in the power train was the bevel-gear and inclined shaft by C. and G. Cooper of Ohio around 1900. This made it possible for the farmer to convert his portable steam engine into a traction engine. Around 1910, selective-speed, ratio-type transmissions were common, although many still had only one forward speed. Friction drives and planetary gear transmissions were not uncommon. In 1941 the average tractor tested at Nebraska had four forward speeds. The number of forward speeds had increased to an average of eight by 1961, and in 1968 the newest transmission had an infinite number of forward speed ratios.

Transmissions have evolved in the following rough sequence:

- Basic selective-gear, fixed ratio, plus a manually operated dual range
- As above, but with a hydraulically operated dual range
- Full power shift "on the go" units
- Gear transmissions plus hydrostatic drive
- Manually or hydraulically operated dual ranges plus hydrostatic drive
- Full hydrostatic drive

  (Although an important improvement, the gear-transmission, torque-converter combinations are an offshoot from this sequence. There has been considerable leap-frogging of these classifications by manufacturers in order to beat the competition.)

The conventional selective-gear transmissions consist of the sliding-gear and constant-mesh types, trending recently towards the latter. John Deere introduced a refinement of the constant-mesh type in 1960, the "Synchro-Range" with some "on the go" shifting. Although power is actually disconnected, the completely mechanical unit shifts without the tractor coming to a complete stop.

Other than additions of gear ratios, the first major breakthrough came with International Harvester's "Torque Amplifier" in 1954. Next came Minneapolis-Moline's "Ampli-Torc" in 1955, followed by the Allis-Chalmers "Power Director" in 1957. These were among the first tractor transmissions that changed output speed with the tractor in motion while transmitting full power. They consisted of the basic sliding-gear transmissions, teamed with a single planetary gear set. This doubled the number of usable ratios built into the transmission, and as torque multipliers, they changed one speed or ratio without interrupting power.

Around 1955-56, a hydrokinetic torque converter, used with a selective-speed manually shifted transmission was developed. Combination converter and gear transmissions were put in the field by Case, Oliver, and Sheppard in 1957, and by Massey-Ferguson in 1958.

The whole point of the hydraulic or hydrokinetic torque converter is that the output speed, and therefore the tractor speed, automatically adjusts itself to suit the load, without altering the engine controls. The real problem with them is their efficiency, which is low in comparison with gear transmissions: of the order of 80 per cent.

The next transmission improvement was to have the dual-range planetary gear set controlled hydraulically instead of manually. Both Oliver ("Hydra-Power") and Massey-Ferguson ("Multi-Power") launched their designs in 1962. International Harvester changed from manual to hydraulic shifting in 1963, and Allis-Chalmers followed in 1964. But whether manually or hydraulically operated, only one speed or ratio can be changed while the tractor is moving.

The latest group of selective-gear, fixed-ratio transmissions has operator-controlled, full-range power shifting; all possible speed changes are made without stopping the tractor or interrupting power. The full-power-shift transmission consists of three or four of the hydraulically-operated, planetary gear sets. The first transmission of this type was Ford's "Select-O-Speed" in 1958 followed by Deere's "Power Shift" in 1964.

Hydrostatic drives began the so-called higher levels of transmission improvements. The first of several possible intermediate combinations mates the basic gear unit to a hydrostatic drive, such as in the Case, Deere, and International Harvester self-propelled combines. In England, Roadless Traction Limited marketed this system in a tractor in 1964.

Basically, hydrostatic transmissions or drives consist of a hydraulic pump feeding, through hydraulic lines, to one or several hydraulic motors. Either the pump or the motor or both have variable displacement. The operator controls this displacement and this results in an infinitely variable series of speed ratios. The trouble with hydrostatic drives, as in hydrokinetic converters, is that they are inefficient. Hydrostatic drives seldom deliver more than 80 per cent efficiency, compared with 95 to nearly 100 per cent efficiency for almost all gear transmissions.

The ultimate in hydrostatic transmissions is the direct conversion of engine torque and speed from an engine-mounted pump to low-speed, high-torque motors that drive from within the wheels. British engineers displayed one in 1954 in what was billed as "the world's first gearless tractor".

In 1961 International Harvester publicly demonstrated a tractor using a full-fledged hydrostatic transmission. The HT-340, a research tractor developed from the 340 utility tractor, had a gas turbine engine and hydrostatic transmission using radial hydraulic motors in the drive wheels.

In 1967 International Harvester started production of their new model 656 hydrostatic transmission tractor. It offers, in effect, an infinite number of gear ratios, without gears. Speed may be varied from 9 mph in reverse to 20 mph in forward, smoothly and without interrupting power. A two-speed ratio conventional gear unit was placed in series with the hydrostatic unit to give a high-low range selection. Fuel consumption will be slightly higher because of the low efficiency of hydrostatic drives compared with conventional constant-mesh gears.

As *Implement & Tractor* puts it:

> The advantages of a hydrostatic transmission include infinite selection of speeds, smooth speed changes, built-in braking, fast reversing, fewer working parts . . . but it all adds up to a more precise match of power to operating needs -- or high productivity.

Traction: Getting the Power to the Ground

Shortly after 1900, the wheel-type traction engine manufacturers attempted to solve the traction problem by simply making the drive wheels bigger and wider. But by 1916 small-diameter steel drive wheels (about 50 inches in diameter), with four-inch or bigger "spade lugs", which gave greater traction than large-diameter wheels with low cast or angle iron diagonal cleats, had been adopted generally.

By 1920 some experiments had been made with rubber tires. Around 1928 citrus growers in Florida started putting discarded tire casings on their tractors' steel wheels to protect the roots of their trees. The tire manufacturers noted this development and in 1931 the B. F. Goodrich Company developed a zero-pressure tire. The zero-pressure tire was actually just an experiment and was pre-empted by the pneumatic tire. In 1932 several manufacturers were experimenting with low-pressure tires and in the same year the University of Nebraska initiated research into pneumatic rubber tires. By 1934 at least one manufacturer was offering pneumatic tires as standard equipment.

There are many advantages of rubber tires, and they include easier riding and reduced vibration, reduced wear on tractor parts due to the tires absorbing shock loads, higher field speeds that allowed a 50 per cent increase in draw-bar power and greater resistance to rolling, and the ability to travel on public roads.

The advantage of using water in tires, to add weight for better traction, became clear. The water could replace the iron weights on the wheels which often caused trouble at high road speeds. An anti-freeze solution was added during cold weather.

Because the load-bearing properties of soils have remained the same, and because of increasing tractor horsepower, the limitations imposed by field conditions on the size and torque-transmitting capacity of pneumatic tires is introducing traction problems of increasing severity. Several solutions have and are being used: double rear-drive tires, dual rear-drive tires, four-wheel-drive and tandem tractors. So far none of these approaches has been entirely satisfactory.

The conclusions of one study of four-wheel-drive conversion kits, which involved taking about one-third of the torque to the front wheels, indicate that this may be one of the most practical approaches to obtaining more usable draw-bar power in the medium-horsepower tractor.

In 1963 Russia entered the horsepower race when they began production of the K-700 tractor. This is a 12-ton, four-wheel-drive unit for field use and heavy hauling, with a 210-220 HP engine. Its draw-bar pull is approximately 18,000 to 20,000 lbs.

In recent years seven companies have come out with large four-wheel-drive tractors of 100 HP or more. Most of them are sold in the West. They are steered in one of several ways: ordinary front-wheel steering, rear-wheel steering, co-ordinated front- and rear-wheel steering, "crab" steering, and fixed wheels with a hydraulically pivoted frame. The Case 1200 has all the first four types of steering, which makes for a highly manoeuvrable tractor, but calls for a complex system of levers, pedals, and ball-joints.

The Versatile G125 tractor also has four-wheel drive. It has 125 draw-bar horsepower, and pivoted frame steering. It is very light for its power and lacks all accessories and "frills" except power steering. It has not, however, been tested at Nebraska to date. Versatile also sells a larger tractor at 145 draw-bar horsepower. All of these tractors have power steering, but lack the PTO (except the Case 1200).

There were two new and interesting traction improvements in 1968. Off-centre drive wheels were introduced as an option on the Ford 5000 tractor. The axles may be changed from being concentric within the wheels to eccentric by about six inches, by flipping a lever. The manufacturer claims a 100 per cent increase in traction for part of the rotation of the drive wheels.

The differential lock, which was introduced by most major companies around 1963, may also be classed as a traction-increasing device: by pushing a pedal, the operator may lock the differential, so that both drive wheels must turn in unison. There is, however, a safety problem, for if the differential lock is left engaged, turning the tractor is almost impossible.

Hydraulics and Hitching Systems

In 1893 there was a steam traction engine with tracks in the rear and wheels in the front, with an engine that could be also used to drive threshers. It was, in effect, a so-called PTO machine.

In 1918 International Harvester introduced a practical power take-off (PTO) for its tractors. It permitted direct-transmission power from the engine to such equipment as mowers, small combines and sprayers. As this was a very useful improvement, most tractor manufacturers soon had their tractors so equipped, and they started to fit many of their field machines for power take-off drive. This PTO would be classed today as "ground-driven", in that it only operated when the tractor was moving and at a rate proportional to the ground speed of the tractor. This was a serious limitation and the "live" PTO or engine-driven PTO did not come out for several years.

A marked improvement was the continuous-running PTO offered in 1947 by Cockshutt. The continuous-running or live PTO allows the operator to stop the motion of the tractor without stopping the PTO. The same may be done with the independent PTO which was developed later. The "live" PTO is used with a double clutch, so the tractor must be stopped to stop the PTO. With the independent type, the PTO is operated independently of the power train.

Most of today's tractors have either the "live" PTO with double clutch or the independent PTO which offers "ground-driven" and "live" operation. Some of the large four-wheel-drive tractors, however, have no PTO at all.

In 1936, the first rear-mounted, hydraulic, rock-shaft power lift was produced. There had been structural and mechanical problems with the older mechanical power lifts, and the hydraulic type thus made possible the use of heavier deep-tillage tools and associated equipment.

A related development of great importance was the "Ferguson system". Harry Ferguson, in Ireland, conceived of the idea of using the hydraulic power lift to automatically vary the working depth of an implement in order to maintain a pre-determined draft rather than a pre-determined working depth. The complete system comprised of the hydraulic pump with draft-responsive control system, lifting cylinder, rock-shaft lifting arms, and his previously developed three-point hitch, was marketed on the Fordson tractor, through an agreement with Henry Ford, in 1938. Although his agreement with Ford did not last, his system has since been taken up in various forms by other manufacturers. Because of its successful revolutionary nature, it is standard on most of today's tractors.

Trends to bigger tractors and to heavier implements have prompted the need for a fast, easy way to attach and detach mounted implements. The industry responded by bringing out a variety of types, some of which completely abandoned the three-point hitch which was standard throughout the industry. Standardization soon became necessary.

The quick-attach coupler which was adopted was an arch-shaped (inverted U) frame used between the tractor's three-point hitch and the implement's attaching points, with a long, tapered upper hook and two lower sockets. Latching and unlatching mechanisms held the implement hitch pins. In 1960 John Deere introduced a quick-coupling hitch system compatible with this standard. A number of other companies followed suit.

Weight transfer did not become important until after the Second World War, when the ratio of tractor power to tractor weight increased rapidly. Today all the major manufacturers have weight-transfer hitches for use with mounted implements. Only four have them for trailing and semi-mounted implements.

The early weight-transfer hitches used the familiar three-point hitch, with essentially the dimensions of the present Category I three-point hitch. The control system was arranged to respond to changes in the compressive force in the top link produced by variations in the draft load. When draft load exceeded a pre-set value determined by the operator-controlled hand lever, the force in the top link actuated the hydraulic-system control valve to admit oil to the lift cylinder, and thus attempted to raise the implement by the two lower links.

In attempting to lift against the weight and the downsuck of the implement, the hitch also attempted to lift the front end of the tractor. In doing so, weight was, in effect, transferred from the front to the rear wheels of the tractor -- thus the term "weight-transfer" hitch. These hitches worked well only with mounted implements with significant downsuck.

With the continuing increases in tractor power and implement weight, stability became a problem when the implement was in transport. A remote hydraulic cylinder was attached to the implement to lower one or more wheels for transport. The next development was an integration of the hydraulic actuation of the implement wheels with the tractor hitch system so that regular hitch action was supplemented to prevent excess weight transfer and the resulting stability problems when the implement was in the working position.

Now, however, Allis-Chalmers, Massey-Ferguson, David Brown, and Oliver provide hitch arrangements that produce weight transfer with a variety of trailing-type implements or machines. All of these systems are different, and only two may be used with competitive tractors. On both the Allis-Chalmers and Oliver systems, weight transfer increases with increasing draw-bar load, but the Massey-Ferguson systems are controlled by the operator. In all of them, the draw-bar is free to swing in the horizontal plane, but the hitch freezes movement in the vertical plane so that when the lift links rise, they tend to lift the trailed implement by its tongue, thus producing weight transfer.

Although tractor hydraulics got their start before the war with hydraulic lifts and the "Ferguson System", there was little new development work done during the war. However, extensive work was done by the manufacturers towards applying hydraulic remote controls to drawn implements. Much standardization work was done on hydraulics and hitches, jointly by the SAE and ASAE.

Hydraulic systems have become standard or optional on practically all models of tractors. The hydraulic system includes an oil receptacle, pump, valves, and control levers within reach of the driver, all connected by means of high pressure hoses to a power cylinder, which can be located on any part of the tractor or trailed implement where control is desired. Among the uses for it on present-day tractors are depth control, draft control, power steering, power brakes, weight-transfer systems, front-end loaders, back hoes, and remote hydraulics.

In the early sixties a John Deere study of tractor sales and usage showed that most farm tractors were factory equipped with a rock-shaft (which is a central hydraulically turned shaft, to which the lift arms are attached), one remote cylinder, and power steering. Much of the work on tractor hydraulics was done after the war. There were, however, a number of separate hydraulic circuits, one for each major function. In 1963 a central hydraulic system in which a pump or power source provides for all hydraulic operations was introduced on the Ford 6000 and the John Deere 3010 and 4010 tractors.

Central hydraulic systems may be of two types -- closed centre, and open centre. In an open-centre hydraulic system oil is pumped through the open-centre control valve continuously, returning to the sump except when diverted by the valve to power a specific operation. A closed-centre hydraulic system is analogous to a household water system in that oil is maintained in the system at full pressure, with closed-centre valves releasing it to do work as required. Closed-centre hydraulic systems (which are the more recent of the two) permit simpler valving and circuits in the case of multiple use. Simpler feathering control and instant response are obtainable without waiting for pressure build-up. Peak power requirements are lower. John Deere started work on a central hydraulic system with a variable displacement pump and closed-centre valving in 1963. Allis-Chalmers, also in 1963, came up with the split-pump design, which gives the weight-transfer system its own hydraulic pump for load sensing. This was done to isolate the system from possible pressure fluctuations in the main system.

Tractor Configuration, Convenience and Safety

In 1928 and 1929 Deere & Company produced the first mechanical power-lift for lifting integrally mounted implements. It was offered first on Deere's GP (general purpose) tractor.

In 1935 all Case tractors were equipped with a motor-lift for raising or lowering implements. The lift was driven by engine power through an enclosed worm and gear mechanism. Among the tools developed for use with the motor-lift were two- and four-row corn and cotton cultivators, two-row potato cultivators, ten-row truck crop seeders and cultivators, six-row beet planters and cultivators, four-row corn and cotton planters, three-row "middle busters", two-row listers, and seven-foot mower attachments.

In 1947 Allis-Chalmers introduced a tractor fitted with a device to power-adjust the rear wheel tread spacing. Massey-Ferguson, Ford, John Deere all followed suit in the 1950s. Today all the major tractor companies offer this convenience.

One of the more interesting of recent tractor developments -- it cannot be considered an improvement yet -- is the automatic or remote-control tractor. The advantage of a remote control or automatic tractor is that it takes the farmer out of the field away from safety hazards and, in the case of the automatic tractor, allows him to do other work.

Much development and experimentation has been done on automated tractors. Tractor guides, which automatically steer the tractor until the end of a row, of the furrow follower-type were on the market during the fifties but they never gained widespread acceptance. In 1958 at the University of Nebraska a tractor was radio-controlled, and the tractor could be stopped, started, steered, and have its gears shifted. Also in 1958 two research engineers working independently announced the development of an automatic tractor pilot -- L. A. Liljedahl of the United States Department of Agriculture and C. B. Richey of Ford. In the Ford system, the sensing antenna for the steering controls is between the front wheels of the tractor and picks up its signals from a small wire buried under the field. A second antenna receives start and stop signals over the same wire to control clutch and brake.

Engineers of the University of Reading, England, in 1959 demonstrated a tractor controlled by a wire laid along the ground or just under the surface. Controls were available for steering, starting and stopping, operating the clutch, power take-off, horn and other mechanisms.

In Canada, Dr. F. V. MacHardy of the University of Alberta did some recent work on an automated tractor. In 1968 it was at the model stage only.

Prior to 1910 the frames of wheel tractors were built up of channel iron, to which the engine and other parts were bolted.

Most large drive gears were of cast iron, exposed to the dust and dirt, and they wore rapidly. The built-up drive wheels, often six-feet and sometimes eight-feet in diameter, turned on a one-piece axle.

In 1913 the Wallis Cub appeared; it was a 3-wheeler and of compact design, but it also introduced a revolutionary development -- a frameless-type construction. The one-piece, U-shaped crank-case and transmission housing of boiler-plate steel was the backbone of the machine. Other manufacturers soon followed suit. The Fordson, built in 1917, was also of unit-frame construction, but of cast iron instead of boiler-plate steel.

The large tractor, seemingly the predominant type in 1910-20, could not accomplish the many tasks necessary to mechanize the farm -- it could only plow, drive threshers, and pull large headers. Light tractors did not appear to be the answer either, because they could not do the things the large tractor could. An all-purpose tractor was needed.

In 1914 the Moline Plow Company started production of the Moline Universal, which was one of the earliest practical approaches to a general purpose tractor. But the first commercially successful all-purpose tractor was International Harvester's Farmall, in 1924. It was a two-plow size and could cultivate four rows. It had high rear-axle clearance, small closely spaced front wheels to run between rows for cultivating, and a hitch for cultivators and other equipment. This type of tractor is now called the tricycle "row-crop tractor". Similar machines were soon produced by other companies.

Tractor safety has at long last become a major concern of tractor manufacturers. Tractor upsets, the major type of tractor accidents, have prompted many companies to do research into tractor cabs and roll-bars and now at least two major companies offer them as options. In Sweden, however, roll-bars, or some other type of safety frames, are compulsory. A number of other safety features have been incorporated in tractors, such as not being able to start the tractor in gear. But much work remains to be done, especially on brakes.

Track-layer development started around 1850. In 1870 there was a steam, three-track, crawler tractor at work plowing in Iowa.

The first practical, commercially produced track-type tractor, however, was built by Alvin O. Lombard of Maine in 1901, for the logging industry. It was of the half-track type.

The steering system used on the caterpillar tractors of today, whereby a change of direction is accomplished by turning one track faster than the other, was first used by Benjamin Holt on his steamers in 1904 in Stockton, California. Holt built only eight of his steamers and began to replace them by gasoline-powered engines in 1907.

Before the Second World War, the track-type tractor was the power source used for much of the tillage and earth-moving needs in Western North America. Smaller "orchard" models provided the positive traction and short turning ability required to pull offset disks and other equipment through orchards, groves and vineyards. The 60, 80 and 100 HP track-type models were the only large power sources available for open field operations. As a result, the wheeled tractor was relegated to the roll of utility work, row crop cultivation, and smaller farm operations. The flotation effect secured through large areas of track in contact with the ground could not be equalled by the early wheeled-type tractors with steel wheels and lugs. Only in fairly recent periods have very large rubber tires become available, to open the possibility of using more powerful units without excessive slippage.

During the 1959-64 period a gradual change took place in the traditional track-type power pattern. The largest track-type tractors then being used in the construction industry became too large for practical use in agriculture. Although the grower is always interested in economical use of more power, it did not prove to be practical to provide implements for track-layer tractors over the 150-180 HP range due to transportation problems and manoeuvrability. The 80 to 120 HP range was satisfactory for most large western farms. Rubber-tired tractor power began moving out to western farms in the same way it moved into the heavy construction industry. Farmers found that rubber-tired tractors could provide effective power at a lower total cost even for their heavier tillage operations, with ground pressures equivalent to those achieved with tracked tractors, and much more operating flexibility.

Fuels, Lubrication, and Hydraulic Fluids

Around the mid-1930s, with the co-operation of the major oil refiners, the octane rating of regular gasoline was increased to a minimum of 70 from the previous low of 50. This permitted the increase in compression ratio of tractor engines with the resulting thermal efficiency. Oliver, followed by Minneapolis-Moline, came out with a new tractor engine designed with a high compression ratio for use with the new 70 octane regular gasoline. Others followed suit, and by 1949 no more low-octane distillate engines were being built.

Octane ratings of regular gasoline advanced quite rapidly until about 1961 but have not changed much since then. A gain of approximately one per cent in fuel economy is available for each octane-number increase if the engine is developed to utilize the improvement in the fuel. Compression ratios of tractors lag behind autos mainly because the tractor engine must sustain a high load factor continuously.

In 1941 Minneapolis-Moline introduced the first standard tractor fitted at the factory for burning another type of fuel for tractors -- LP (liquefied petroleum) gas. Some companies had offered kits for converting the tractors in the field from gasoline or kerosene to LP gas.

This LP gas, a "light end" fraction of crude oil, had been largely a waste product until means had been developed to liquefy it by compression. While the cost of LP gas and gasoline is similar per unit of work, LP gas has advantages in that it burns cleaner and causes less oil dilution. Tractors converted from gasoline to LP gas must have the proper compression ratio, intake manifolding and spark timing. Not all LP gas conversion kits will do a complete conversion job. Gasoline, however, is usually more readily available and the engine is easier to start on cold days.

Although draw-bar and PTO dimensions have been standard for years, there is a need for hydraulic fluid standardization. Fluid standardization would permit the user to operate hydraulically-controlled equipment with different make tractors with no fear of damage caused by intermixing fluids.

Tractor engine oil service requirements have become more severe. BMEP (brake, mean effective pressure) and oil sump temperatures have risen to the point where only a few oil types are tested at BMEP levels found in current engines and only one oil type is tested at current typical sump temperatures.

A University of Illinois survey also pointed out that 70 per cent of tractor operators did not understand the API Service Designations for engine oil. In contrast, 96 per cent understood the SAE viscosity classifications.

Materials and Manufacturing Techniques

There have been many other less spectacular and hidden improvements in tractors, things such as alloying and deep-drawing and forging practices, improved steels, journal bearing improvements, anti-friction bearings, air and oil cleaners, clutch and brake facings, disk brakes, heat-treating practices, valves, valve seat inserts, valve rotators, spark-plug improvements, and improved ignition systems.

Gear manufacturing practices have changed. In 1916 hardened steel gears were used throughout the power trains, and the acceptability of hardened alloy-steel bevel gears, with generated straight or spiral teeth, mounted on adequate radial and thrust bearings, had been established for tractor use. Prior to this, most gears had been cast iron. In 1920 alloy and heat-treated steels along with anti-friction bearing (ball bearing, roller bearings, etc.) were coming into use.

In 1948 there were only a few tractor transmissions with helical gears throughout. Bevel and spiral bevel gears in the transmission were coming into use. Alloy steels were used widely. Most transmission gears were made from low-carbon steel, carburized and hardened. The use of gas carburizing and direct quench were beginning to be used on gears as well as cyanide hardening, induction hardening and flame hardening. Local hardening of the teeth using the latter methods was coming into practice.

APPENDIX C

HISTORY OF THE DISKER

by

Audrey Doerr and H. A. Lewis

INTRODUCTORY NOTE

The fundamental purpose of tillage operations on farms is to prepare a satisfactory seed-bed that will produce high yields over a period of years. Tillage is performed with four objectives in mind: conservation of moisture, prevention of soil erosion, control of weeds, and control of insects. Prairie farmers learned the hard way in the 1930s of the dangers of soil drifting, and today's tillage machines for "shallow" cultivation are the direct result of their experiences. The machines that evolved from these experiences are the following in order of development:

Moldboard Plow -- The plow is one of the oldest tillage implements known to man. It was widely used in opening up Western Canada, but its continued use was a contributing factor to the dust storms of the thirties. This erosion showed the importance of trash cover, and limited the use of the plow.

Disk Plow -- This plow was used in heavy clay soils where moldboard plows would not scour. One-way disks, however, came to replace these plows on the Prairies.

One-way Disk -- This tiller was developed by a Kansas farmer and became popular during the 1920s and 1930s. This machine, if used at a reasonable speed, was able to assist in soil conservation by leaving trash to protect the soil surface from wind and water erosion. High-speed operation (over four miles per hour) was found to cause excessive pulverization and reduced the effectiveness of trash cover.

The disker -- This machine, developed in Saskatchewan, combined features of the disk harrow and the one-way disk. It was similar to the one-way disk in appearance. The standard disks of the disker were used in individual gangs, usually three feet in length. Disks could be obtained in several sizes, such as 16", 18", and 20" diameter, and either single-curvature or double-curvature style. It was found that draft and pulverization increased with increasing disk diameter and increasing concavity. Standard disks are considered to be the 18" single-curvature type.

The disker is essentially a shallow tillage implement that will operate to a depth of about four inches. It will cut off weeds without leaving the objectionable ridge of the disk harrow. Trash is left well-anchored to protect the soil from erosion, and more is left on the surface by the disker than by the one-way disk. Thus the disker is an excellent machine for summerfallowing and in combination with a cultivator will do a complete job of tillage.

A very complete and excellent history of the disker has been compiled by H. A. Lewis, a former professor of agricultural engineering at the University of Saskatchewan. I can make no pretence to add to the information in his article, and therefore submit it in its entirety.

A. Doerr

THE DEVELOPMENT OF THE DISKER IN SASKATCHEWAN

by

H. A. Lewis

Most of the agricultural machines in general use today cannot be traced to a single invention or to any one man's development of ideas. As changes take place in farming practices, modifications in farm machines are often necessary to suit the new tillage requirements, or -- as in the case of the disker -- an in-between class of machine seems necessary.

The disker, like many of our present-day farm implements, was developed as an evolution of ideas based on the principles of the disk plow, the "one way" and the disk harrow. During the early 1920s, many farmers in both Canada and the United States, as they used the disk plow or the disk harrow, felt the need for a machine that would accomplish a less severe type of tillage than the plow and yet a deeper cultivation than that provided by the disk harrow. The surface ridging of the soil left after a disk-harrow operation was also objectionable. As a result, the "one way" appeared during 1923 in the Southern United States.

Mr. C. J. Angell of Plains, Kansas obtained a patent on what he described as "a new type of disk plow built with the disks on one axle and moving the dirt one way". His patent was later infringed and upset on the grounds that the principle had been in use in Australia for several years. By arrangement, the Angell One Way was manufactured in volume by the Ohio Cultivator Co. of Ohio. Their machine appeared in Saskatchewan in August of 1925. By 1930 practically all of the major machine companies were marketing "one ways" under a variety of names. However, they were all called "one ways" in the farmer's language.

The "one way" was a cantankerous implement in that it had considerable side draft, required quite a bit of weight for penetration in firm soils, and presented hitching problems that seemed insurmountable to many farm users. The University-sponsored plowing matches had lost popularity by the early twenties and were being replaced by "Farm Machinery Field Days". The hitching and draft problems of the "one way" skyrocketed the demand for field days to demonstrate hitching and adjusting these machines. The Agricultural Engineering Department of the University of Saskatchewan conducted seven farm machinery field days in 1926. The number grew to 120 by 1937 and in 1948 reached a peak of 172 field days for the season. At about that time the use of the disker became general and, with its ease of hitching and minor problems of operation, the demand for field days fell off to 120 in 1951 and by 1957 only a sprinkling of these demonstrations were requested.

The problems associated with the operation of the "one way", and the fact that during the dry period of the thirties many Saskatchewan farmers and research stations discovered that deep tillage was not advisable for our area, created a desire for a machine that would achieve shallow, complete tillage with a maximum of trash left on the surface. Many felt that a combination of the features of the disk harrow and the "one way" might produce the desired effect. Had it been as simple as the crossing of the two machines, similar to the crossing of breeds in the animal world, undoubtedly many such crosses would have been tried. Many farmers, as they went about their farming operations, tried to visualize a machine which would embody the desired features of the "one way" and disk harrow, leaving out the ridging of the disk harrow and the operational problems of the one way.

In the Agricultural Engineering Department at the University of Saskatchewan we had countless men come to see us with part plans, partial ideas, and in some cases just plain problems to which they hoped we might have an answer. In many instances we learned more from them than they learned from us. Since I was personally interested in the whole development, Professor Hardy, the head of our department, asked me to set up a file and keep a record of all the information and ideas we received so that we could use it for reference and information. As I peruse that file it is evident that the origination or first development of the disker cannot be credited to any one individual. Quite a number of people in various points in Saskatchewan, all operating at about the same time, made worthwhile contributions to its improvement. One thing is certain, however, and that is, the development and building of the first successful machines took place in Saskatchewan.

The first operating machine that our department saw working was inspected by Professor Evan A. Hardy in 1930. It had been built by Mr. L. Weckman at Rouleau. His machine was not of the same general type as our present-day diskers, but was flexible rather than using a solid gang like the "one way". It did a similar class of work to the present-day diskers with the side thrust absorbed by wheels and the tractor hitch. It had to be transported from field to field on a long stoneboat as there was no provision to lift the disks out of the soil.

About 1938 we viewed a machine made up by using the right-hand disk gangs from disk harrows attached to a six by six inch timber by drag chains. No supporting wheels were used and all of the side thrust was absorbed by a triangular arrangement of logging chains from the timber to the drawbar of a heavy steel wheeled tractor. The angle of cut was varied by changing the length of the chains. For transporting, the angle was changed until the timber was at right angles behind the tractor and the disks simply rolled out on the surface. Mr. M. T. Allen of Neville made the machine and for several years he sold plans for the construction of this machine for one dollar apiece to western farmers through an advertisement in The Western Producer.

By 1940 several people had visions of machines similar in general principle to our present machines, but in most cases lacked the money, initiative or facilities to actually build a working model. Mr. Russell Fyke at Sceptre had even gone as far as drawing scale plans of a machine which used a three-wheel suspension and independently mounted disk gangs, which he was not able to build until some time later. By that time he was able to borrow additional ideas from builders with proven machines.

At about the same time, 1940, Mr. Fielding, at Eastend, developed a machine which used two very small, flat-faced wheels in front to support the weight of the front frame and act as a hitch cart. It had two vertical wheels from the front end of a Fordson tractor on the back end of a tubular frame to take the side thrust. His gangs were all linked together by universal joints and were pulled by short chains from each gang to the tubular frame. He was not able to build his own machine so he obtained assistance from a Mr. Jensen of the same district. Their machine met with some approval and they later arranged with

Mr. Norman Hall of Shaunavon to build some machines for them in his machine shop. The machine had serious side problems and tended to drag the rear end of the tractor sideways as well as interfering with the steering. For this reason it worked better behind steel wheeled tractors than the recently introduced rubber tire tractors. Under severe operating conditions the disk gang would hump in the middle, leaving some of the land entirely unworked. I first saw one of these machines in operation at a field day south of Weyburn on the farm of Mr. Earnest Kyle in the spring of 1942. While it had many good features I was not particularly impressed with its over-all performance.

All of the ideas and machines up to 1942 were quite varied in their design and in the way in which the weight was carried as well as the methods of absorbing the side thrust. In fact about the only thing that they all had in common was the use of old disk harrow gangs for the main tillage medium. In most cases the absorbing or offsetting of the side thrust was their biggest stumbling block.

During 1942 and 1943, Mr. R. A. Johnson of Beadle visited us several times to discuss his ideas of a machine that would use conventional disk harrow gangs in a flexible type of mounting to a frame somewhat similar to the conventional "one way". He visualized a constant angle to the direction of travel with the main frame and minor gang angle varied through lever control. He also visualized a second lever to apply spring pressure to the rear of each gang as required to maintain a level depth of cut. A third lever or a latch of some sort would lift each gang to a transport position for moving.

We had several conferences on probable loads, strength of materials required, probable draft and consequent size of machine that his IHC WD9 tractor could pull, and the ranges of desirable angles of cut. On one occasion we spent several hours with chalk, drawing up full-scale designs on the smooth cement floor of the tractor laboratory to get the information that Mr. Johnson wanted. Finally he was able to make up a machine in the winter of 1944 and the early spring of 1945 with the assistance of Mr. Dave Johnston, the blacksmith at Kindersley. They used parts from an old tractor frame and a discarded Bissill disk harrow as their materials, keeping down expenses as much as they could until they found out whether it would work or not.

Professor Hardy and I visited the Johnson farm on May 1st, 1945 to see the machine on its trial run. So intense was the interest that quite a crowd gathered to see the machine in operation. With some changes that we were able to make to the hitch and the positioning of the rear wheel, plus extra weight on the rear wheel to assist in holding against the side thrust, the machine worked, as Mr. Johnson put it, "much better than it ever had even as a new disk harrow". Mr. Johnson's machine was the first operating machine in the province, as far as we know, to use the now conventional three-wheel support and two-point flexible mounting of the disk gang to the set angle main frame.

Mr. Leo Wyman, the Massey Harris dealer at Kindersley, had been following R. A. Johnson's work with considerable interest and had started to assemble parts from his repair stock to build a machine of his own. The blacksmith had also started to develop a machine of his own. After the successful trials on May 1st, 1945, they and a number of local farmers requested that a field day be held later in the spring to try out the proposed three or more models that they expected to have ready. Both Mr. Wyman and Mr. Dave Johnston promised to have machines of their own ready to go by the middle of June. Professor Hardy and I attended the field day on June 11, 1945, with two assistants. We planned to test, as we thought, some three machines, but on arrival at Kindersley we discovered that five machines were in the field. They were Mr. R. A. Johnson's original machine, one built by Mr. D. Johnston the blacksmith and sold to Mr. M. G. Cressman, and three Wyman-built machines, one built on rubber-tired wheels and two on steel wheels. He had sold one of the steel wheeled machines to Mr. S. L. Watley, who pulled it with a D2 caterpillar. This was the first time we had ever seen side thrust controlled adequately so that a track-type tractor could be used.

During the late seeding operation, Mr. Cressman mounted a seeding box from an old drill on his machine. The drive was taken from the land wheel. The box was only long enough to serve the front four gangs with seed and the machine was operated with the two rear gangs raised. This machine was very likely the first disker to operate with a seeding attachment.

A crowd of over 500 interested people, some of whom had driven over 200 miles to be present, were on hand. With minor adjustments all of the machines worked well, and I think over half of the people present went home resolved to build a machine of their own. I still look upon June 11, 1945, as the day that the big swing toward diskers started in Saskatchewan. During the balance of that summer and the spring of 1946 I saw and tested more than a hundred machines while several other members of our staff must have come in contact with at least that many more.

Almost every well equipped machine shop or blacksmith's shop and many farmers with good shops started building diskers to supply the local community demand. The limiting factors in production became time and availability of parts. Junk yards were scoured for heavy steel pipe, old plows, "one ways", and other machines were dismantled for wheels, shafting, disks, bearings, etc. A distinct change was rapidly taking place in Saskatchewan tillage.

There were so many commercial builders in operation by late 1945 and early 1946 that it would be impossible to mention them all, and of course there were many good builders that we did not know about at all. For the purpose of record, however, a few that did come to our attention and who were typical of others that perhaps should be mentioned, are listed here.

Norman Hall of Shaunavon, a machine shop operator, built a few machines for Fielding and Jensen, mentioned earlier in this article. From this experience, and having seen a number of other machines, including those at the Kindersley demonstration, Mr. Hall went into manufacturing on a moderate scale. He came to see us in the department on at least two occasions and was able to produce a very satisfactory machine.

Mr. Les Wyman and his sons at Kindersley expanded their shop facilities and for several years taxed the Massey Harris Company rather heavily in supplying the parts which they used in their constructional program. The small factory which they set up for the building of diskers at that time has since been used for the building of several other new farm machines which have been useful in that area.

Fred Schneider at Eston and Mr. M. Poppowill, the blacksmith at Eston, both manufactured numerous machines. Also worthy of mention as small manufacturers were Kennedy of Rouleau, Gregg of Regina, Tindall of Riceton, and many others. In fact, there were not many well equipped machine shops in the province that did not build at least one disker.

The major farm machinery companies were not long in investigating the new development and by 1946 most of them had their engineering staff visiting Saskatchewan to investigate and evaluate the various machines. During this period we became quite well acquainted with many of the influential people in the farm machinery manufacturing field.

A few Saskatchewan men were engaged by the major machine companies to act in an advisory capacity during the development of their own designs.

During the spring of 1946, the Board of Directors of Canadian Co-operative Implements Limited contacted me. Because of the wide study and contact I had enjoyed with this class of machine, they requested that I design and build a prototype machine for them, which would embody many of the good features I had observed in the wide variety of machines that I had tested. I had been planning to build a machine for use on my own farm anyway, and this permitted me to do the two jobs at one time. We built the machine, a six-gang unit, and then tested it by going over all my summerfallow with it. After a few changes and improvements were made, the machine was trucked to the Co-Op factory at Winnipeg. I went to the Co-Op factory and spent some time with them making the necessary modifications on a few parts to conform to factory production procedures. The first machines came off the assembly floor at the factory in August of 1946 and as far as I know this was the first large factory production of the disker as a farm implement.

Up until that time the machines had been referred to under several names, the most common of which was "the wide level disk harrow". The Co-Op management felt that the name was too long and in seeking a shorter name I suggested the term "Discer". The name has caught on, and even though CCIL saw fit to copyright the name as "Disker", it has become the popular name for all makes of machines in the language of the farmers. Because of the copyrighted name, other manufacturers advertise and sell their machines under a variety of trade names.

The Cockshutt Company designed and built a machine somewhat similar to the Co-Op's but of lighter construction. It was on the market in Saskatchewan in June 1947, and proved to be quite a successful machine.

Mr. Les Wyman of Kindersley worked with the Massey Harris Company in the design of their machine which appeared early in 1948 as the wide level disk.

Mr. Fred Schneider of Eston sold manufacturing rights on some of his designs to the American Harvester Company. They were producing machines and marketing them in Saskatchewan from their Winnipeg branch through jobbers late in 1948.

At the same time, Mr. H. H. Hanson of Lajord, who had acted in an advisory capacity to the John Deere Company during 1927 and 1928, when they were producing a western type of combine, again worked as an adviser to the company on the design of their surplex disk. Their machine also entered the Saskatchewan market during the summer of 1948.

The International Harvester Company also introduced their first machines to Saskatchewan late in 1948 and had a good supply ready for the 1949 season.

All of the makes except the Co-Op were equipped with seeding attachments when they were introduced or very shortly thereafter. The Co-Op machine did not have a seeding attachment until 1948.

Since the general introduction of the major line company machines, the production from the smaller shops has been pretty well discontinued. All builders, both large and small, even to the man who built just one machine for his own use, have made worthwhile contributions to the development of a machine well suited to the requirements of our dry land agriculture.

To me, the most important factor in the whole development, other than showing what can be done in Saskatchewan, is that the welfare of our western farmers has been vastly improved by the introduction of a new type of implement which allows them to do a good quality of work at a much lower cost of operation.

The credit for developing the type of implement which we know of today as the disker, must go to a tremendous number of people, all of whom have made their little, but worthwhile, contribution.

February 1964

APPENDIX D

HISTORY OF THE SWATHER

by

Audrey Doerr

> Necessity may have been the mother of the windrower, as she is of so many other inventions, but the combine was certainly the father of this infant of the implement industry.1/

Modern mechanized farming had its beginning during the Industrial Revolution when Cyrus McCormick patented the reaper in 1834. The sole purpose of the original machine was to cut the standing grain and lay it in such a fashion that it could easily be raked and tied into a bundle. The next step involved stacking the bundles in "stooks" in the field, ready to be carried to the threshing area where the grain and chaff were separated by the use of a flail and later by the use of a stationary threshing machine.

Thus the first era in the evolution of harvesting methods involved a relatively simple machine that performed one basic operation. Later refinements to this operation came with the development of the binder. However, no thought was given to connecting the operation of cutting the grain with any other step in harvesting procedures. The development of threshing machines followed in logical sequence. The machines could be horse- or tractor-drawn from field to field, but they remained stationary during operation. Initially their source of power were steam engines.

The increase in output and production that these machines afforded the farmers of the day is obvious. However, many problems remained and new ones evolved as a result of such mechanization. The combine, a refinement of the threshing machine, permitted grain to be cut and threshed in one operation, but for the most part the combined grain was graded "tough" when shipped, because it was not permitted to dry or ripen properly.

Thus the swather, or windrower as it is called in the United States, was developed as a result of the need for adapting the combine reaper-thresher to more effective harvesting operations. In the harvest of grain using the straight combining method, problems arose with respect to weather conditions and grain

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1/ A. P. Yerkes, "Windrower - Offspring of Combines", Combine Year Book, Madison, Wis.: Clarke Publishing Co., 1929, p. 24.

diseases. The chief advantages of swathing were to forestall loss from frost, insect and fungus damage. By cutting the grain and leaving it in windrows to come to ripeness on the stubble, many of these difficulties could be overcome. Thus the swather provided a solution to these problems. Air was allowed to pass freely through the swath and dry out the grain or green weeds before threshing was undertaken.

The first swather to appear in Western Canada has a history that can be traced back to a homestead in South Dakota during the early decades of this century. The Western Development Museum in Saskatoon has this same machine, the Hovland swather, on display in a showroom. The story of its development has been recorded by Mr. Helmer Hanson, a farmer from Lajord, Saskatchewan. His article, first written in 1954, and republished in 1966 in *The Western Producer*[2/] tells the story in detail. Only the most relevant parts have been incorporated into this discussion. To begin:

On the homestead of Mr. Aug. Hovland on the Sisseton Wahpaton Indian Reserve in South Dakota, threshing machines were used as early as 1894.

"Always of an inquiring mind, he studied the problem of threshing and its high cost to the farmer. He had noted that bound sheaves left on the ground any length of time were sure to be moulded and sprouted, he also noted that untied sheaves — 'binder misses' — left loose did not seem to spoil — the inference was that if the grain got sufficient air it did not spoil. Next he started breaking bands and laying a sort of windrow in short stretches on his own farm." After a number of years of planning and designing, Mr. Hovland applied for a patent on a "Centre Delivery Reaper" on February 25, 1907. On April 21, 1908 he was granted patent No. 885157 on the machine.

"First, Aug. Hovland organized a Stock Company with $150,000 common stock authorized, $10,000 subscribed. With this capital the five shareholders held their first 'stockholders meeting' on March 9, 1909. In the first part of May, 1909 Aug. Hovland and

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2/ The quotation in the following two pages are taken from Helmer Hanson, "History of Swathing and Swath Threshing", The Western Producer, Vol. 43, No. 28, Feb. 10, 1966, p. 21.

his brother Ole C. Hovland started making detailed drawings of parts required for building these machines. A small office on Washington Street in Minneapolis was rented for this purpose."

This first "Centre Delivery Reaper" or "swather" was a push-type machine hung on the front of a tractor. "This tractor was an assembly job in part, to suit the special purpose in mind. It looked about like a big 4 tractor or an Aultman and Taylor; or a Twin City tractor; except for the front end where a special lift was built on. This tractor had 8 foot high drivers, 24 inches wide, and quite far apart, the same as on the above tractors. The front wheels on this tractor were 5'4" high, that meant a high clearance axle. The axle itself was of the stiff king pin type like an old steam engine, or like a wagon. The axle extended out through the front wheels on both sides 16 inches. In each of the front wheels was mounted an internal bull gear, for the purpose of supplying power to drive the mechanism of the 'Reaper'. ...This whole 'Reaper' was hung and controlled from the front of the big tractor, both as to tilt and height of cut. It was built to deliver a swath or windrow to run back between the drivers of that big tractor. This was not only the first 'Reaper' - swather - it was push or self-propelled,..."

In addition the Hovland brothers built a "Travelling Thresher", a type of combine designed to pick up the windrowed swath. It could adjust the level of the machine so as to travel over hilly fields.

"To understand what Hovland had built, you must see his plan in detail, also as a whole. He built each unit to work separately. 'The Reaper' was to be propelled by the big tractor and lay a swath to be picked up by the 'Travelling Thresher', or when grain was ready to straight combine he just hooked the combine to the drawbar after coupling the power take off. He then cut a swath of 30 feet, ran it back under the big tractor and picked up and threshed it then and there. It was a flexible unit. He even had a straw spreader on this Thresher."

Mr. Hovland tried to interest eight of the big thresher companies with his new design but none was interested enough to send an officer or engineer to inspect these machines in the shop or field. Mr. Hanson attributed this disinterest to the fact that Mr. Hovland's ideas were ahead of his time.

Mr. Hanson's story then turns to the Saskatchewan scene. He explains how he and his brother built similar models along the line of the original Hovland machine. They did not apply for patents. They used their machines in 1926 and 1927. In 1927 International Harvester Co. sent an engineer out from Chicago to inspect the Hanson models. "The International Harvester Company built and sold the first swathers. They were centre delivery and were cut back as suggested. They afterward went to inside end delivery."

The usefulness of the machine was acknowledged during the first few years of production but its popularity was not widespread. A survey conducted by the *Nor'West Farmer* magazine, published in Winnipeg, reported:

> Generally speaking, the replies were in favour of buying a swather. In fact, many stated that in their particular districts the combine was useless without the swather. Others stated that several improvements would be necessary before the swather would give satisfaction. This latter statement, of course, is not surprising in that the swather is a comparatively new machine, not forgetting the fact that combines, headers, etc. were used in Western Canada during the first decade of this century.3/

A paper presented at the meeting of the Power and Machinery Division of the American Society of Agricultural Engineering at Chicago in November 1927 by Professor E. A. Hardy, Department of Agricultural Engineering, University of Saskatchewan, contained the following report:

> Conditions existing during the 1927 harvest were favourable for testing the method of swathing the grain in connection with the combine. Grain was swathed with binders, headers and swathing equipment designed especially for the purpose. There were sixteen swathers used in Saskatchewan, cutting and swathing about three thousand acres of crop. The twenty-five swathers used in Alberta have averaged about three hundred acres per machine, totalling seventy-five hundred acres of crop.4/

The type of swather that was manufactured for sale varied from the Hovland model. First, it was designed to be pulled, not

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3/ "Opinions on Swathers," in Nor'West Farmer, Vol. 48, No. 7, Winnipeg, Canada, April 5, 1929, p. 5.

4/ E. A. Hardy, "The Combine in Western Canada", from Present Status of 'Combine' Harvesting, ASAE Papers presented November 1927, Published by the Society at St. Joseph, Michigan, March 1928, p. 20.

pushed. The mechanism was simple, consisting of a cutter-bar, reel, and platform canvas or canvasses. The cutting width ranged from 12 to 16 feet. However, the swather was not destined for immediate widespread use. Depression followed by war curtailed the production and use of the machine.

Swathers came to be used extensively from 1948. Prior to that, a good many binders were being used and modified by farmers to make their own machines that would, in effect, do the swathing but not as satisfactorily as production machines.[5/]

Versatile Manufacturing Ltd. in Winnipeg produced its first swathers for sale in 1954. Their first test models were built in 1953. The general principle of laying a swath has not changed, but since 1954 some modifications have been developed. For example, an adaptation called a crimper was made for cutting hay. This would make the swather more useful for haying by cutting, swathing and conditioning the hay in one operation. Larger motors have also come into use throughout the years.

In 1966 Versatile brought out a model change that could move canvasses from one end to the other. This meant that the farmer could either centre-deliver or, in the case of a lighter crop, he could end-deliver and therefore make a 40-foot swath instead of a 20-foot swath.

The first self-propelled swathers were made about 1951 by the Owatonna Company and probably about the same time by Killbery Industries in Winnipeg. They both worked under the same patents of a gentleman in the New Ulm area of Minnesota.[6/]

The cost difference between self-propelled and pull-type swathers is substantial. For example, a 20-foot self-propelled (double swath) machine, equipped with variable reel speeds for changing crop conditions, dual wheels for maximum traction and stability, and Steer-O-Matic transmission, was listed at $3,550. (An adaptation on the machine offered by Versatile self-propelled is the fact that it can be converted into a self-propelled sprayer.) A 20-foot pull-type, with centre delivery, was listed at $1,595.

5/ R. E. Robinson, President of Versatile Manufacturing Ltd., Letter to the Royal Commission on Farm Machinery, June 12, 1968.

6/ *Ibid*.

Versatile is the only centre-delivery pull-type swather on the market.[7/]

According to figures provided by the respective companies for 1967, Versatile held the largest share of the market in dollar sales of swathers and windrowers. The rest of the market was fairly evenly distributed among Massey-Ferguson, International Harvester Company, John Deere, and CCIL.

7/ 1968 Versatile Sale Sheet.

APPENDIX E

THE HISTORY AND DEVELOPMENT
OF THE COMBINE

by

Bruce D. Narsted

The combine is a combination, as the name suggests, of two older machines, the reaper or harvester, and the thresher. The names of these two machines come from the names of the two basic operations in the harvesting of wheat or other small grains before mechanization took place. The first basic operation is the cutting of the grain stalks and gathering them to some central location. The second is the removal of the grain from the stalks and then separating the grain from the chaff — in a word, threshing. Today's combine does this all in one operation.

The Reaper

The first record of grain harvesting machine is the Gallic "stripping-header" described by Pliny in the first century, and by Palladius in the fourth century. Most likely an animal pushed this implement. It functioned by combing or tearing the grain heads off the stalks, whereupon they fell into a bin for later threshing. It is not clear whether a man was required to walk alongside and place the stripped grain heads into the container.

There were no further records of any harvesting devices until 1794 when the "Society for the Encouragement of Arts, Manufacturing and Commerce" in England noted that William Pitt, in 1786, had perfected a machine for "rippling" corn (grain). Between that year and 1831, over 50 different kinds of reapers appeared in England, Europe and the United States. But as Phillips notes, "The numbers, though impressive, reflect the persistence of the inventors rather than the progress being made".[1/]

In 1831, the first commercially successful reaper was invented by Cyrus McCormick. Fatefully, he did not patent it until 1834, for in that year Obed Hussey patented another successful reaper.

A vigorous rivalry began between the two men and their inventions, resulting in much publicity for, and public acceptance of, mechanized harvesting. These machines were little more than horse-drawn mowers, and the next logical development (1858) was the harvester, which allowed one or more men to stand on the machine and bind bundles of grain as it was cut. The automatic binder soon followed.

1/ W. G. Phillips, The Agricultural Implement Industry in Canada, Toronto: University of Toronto Press, 1956.

The header was a machine that did roughly the same thing as the harvester, except that instead of binding the grain, it cut just the heads off the straw and elevated them into a wagon that followed alongside. The grain was then taken to a thresher.

These machines, with improvements and the advent of tractor power, continued to be used until the 1920s when the combine became more universally available, although, as we shall see, the combine began to supersede the header as early as 1880 in California.

The Thresher

The so-called ancient method of harvesting grain by flailing and treading, and then winnowing by tossing the grain into the air and letting the breeze blow the chaff away, was still in use in some parts of the United States as late as 1850, and in 1820 it was "the customary method".[2/]

The first thresher to combine the operations of threshing, separating and winnowing into one mechanical operation was built in Scotland around the year 1800. Several of these machines, apparently with just the threshing feature, were introduced to the United States about the same time. The Americans were not long in building their own machines. One of the most successful was invented by Jacob Pope. It used flails attached to a hand-crank-operated shaft to beat the grain from the heads.

About 1830 a thresher was reportedly built which used a spiked-tooth cylinder and concave. This method gradually came to be used by almost all manufacturers.

The thresher-separator, also introduced in the 1830s, was able to separate the straw from the grain. The winnowing was generally done by a separate machine, the fanning mill. This addition of a straw separator was perhaps the most important in respect to decreasing the labour required for grain harvesting.

By the 1850s, the thresher-cleaner, as the thresher-separator with winnower was known, was generally adopted. Many of the threshers around this time were powered with "horse-powers",

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2/ Leo Rogin, The Introduction of Farm Machinery, Berkeley, Calif.: University of California Press, 1931.

or treadmills. These machines were also continuously improved and used up until the 1920s, when they were gradually abandoned in favour of the combine.

The Combine

The first record of combine development is an 1828 patent found in the United States Patent Office for a harvesting machine. It was taken out by Samuel Lane of the State of Maine. Although there is no record of it ever having been used in the field, its importance must be noted, as it was the first of many machines which laid claim to being able to harvest and thresh in one single operation.

Between 1828 and the 1850s a number of harvester-threshers appeared in North America. Several of today's combine component mechanisms had their start at this time: the endless belt or apron to deliver the cut grain to the threshing cylinder, winnowing by air blast from a fan, the threshing cylinder and concave. Most of these machines did the complete job of harvesting, threshing, cleaning and bagging grain. However, although some of them were quite successful, they all required a large complement of men and horses or mules to operate them.

Another disadvantage was that most of them used the "stripper" principle for harvesting -- that is, they would cut or pull the heads off the grain straw, and in parts of North America the soil was not firm enough, so the plants tended to be pulled out by the roots and the machine would be jammed.

The combine in America appears to have got its real start in California, where the all-important moisture content of ripe grain was low enough to permit mechanical threshing, and wheat growing was a prominent industry. In 1854 one of the more successful of the early harvester-threshers was introduced to California from Michigan where it had been invented in 1836.[3/] It was quite successful and, although it was accidently burned in the field, a replica was built and commercially used.

3/ This date would make the Michigan Combine contemporaneous with McCormick's invention of the reaper. The combine was not successful in Michigan because of problems arising from the
(Continued on p. 123)

From the 1860s to the 1890s a large number of highly successful combines were built, mainly in California. The "Centennial Harvester" built by the Holt Manufacturing Company in the 1890s was typical of the latter part of this period. It originally had been a push-machine but was later changed to a pull-machine. It was first constructed with a six-bar threshing cylinder, 32 inches wide and 21.5 inches in diameter. Its header took a 16-foot cut. It had two drive wheels, with the separator being located behind the header and the wheels at each end, the separator being pushed broadside after the header. The left-hand wheel, operated with crown and pinion gears, drove a long rod which drove the threshing cylinder and separator. The right-hand wheel in the same manner drove the header. When it was changed to a pull-machine, the drive wheels were changed to each side of the harvester or header and two front wheels were added. The cylinder was later increased from a six-bar through to a twelve-bar.

Another of the better known machines at that time were those built by Daniel Best. Best was the first to develop and build the first large, successful steam tractor for heavy draw-bar work, and in 1889 he designed and built the first steam-powered combine-harvester.

The early Best Harvesters, and in fact almost all previous machines, derived the power for operating their mechanisms from a ground-drive wheel. There were many objections to this type of drive, chiefly, the difficulty of maintaining, under varying conditions, the uniform speed that is essential to successful threshing and grain separation. Another major disadvantage was the large number of horses required to pull the machine (40 or

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(Continued from p. 122)

moisture content in the grain. Until the swather was invented and reinvented (see Appendix D) to perform the function of the reaper and binder to allow grain to dry and finish ripening in the field, the use of the combine was limited to areas where grain would fully ripen and dry out in the head, e.g., Texas and California. The prototype Michigan combine performed satisfactorily in the dry areas of California. One of these old wooden combines is on display at the Smithsonian Institute in Washington. Cf., Alfred Stefferud, ed. Power to Produce, United States Department of Agriculture Yearbook, Washington, 1960, p. 165.

more in some cases). Best's steam-powered combine got around this problem by using the steam engine to power the header, cylinder and other parts requiring power. It was not long before all combine manufacturers followed this lead, but these "first engines were so heavy as to offset the reduction in draft due to wheel traction, with the result that about as many horses were required to pull the machine as before".[4/]

Another development of almost comparable importance was the introduction, in 1885, of link belts and V-belts for all drives, on a combine by the Holt Brothers. These early V-belts were of laminated leather strips riveted together, and they did manage to eliminate the clumsy, noisy gears.

Holt's first Harvester using belts was sold in 1886, and required 18 horses to pull it. It had a tubular, cast-metal threshing cylinder with teeth, a header with a 14-foot cut, V-belt drive to the cylinder, link-belt from the main drive wheels to the counter-shaft, and link-belts driving the straw carriers, grain carriers, beaters and cleaners; other drives were leather belts. In its first year it averaged 25 acres per day, and when it was finally sold by its owner in 1905, it had harvested 50,000 acres of grain.

The Hill-side Harvester was first built by Holt in 1891. Like most of the early combines, excepting, of course, Best's steamer, it was ground-driven and horse-drawn. Horses were still being used with Hill-side combines as late as 1920 because of the instability of the tractor on a slope.

The Holt Company was also the first to apply a gasoline engine to the combine. (The combine they applied it to in this case was, in fact, a Hill-side combine, riding on caterpillar tracks.) The specifications of Holt's combine included the automatic levelling shoe, automatic levelling cleaner, split straw carrier and large roller bearing threshing cylinder.

Holt soon became the leading combine-harvester manufacturer in North America. Some of the developments they have to their credit include the largest machine ever made (it took a 50-foot cut); the enclosed grain cleaner, the overshot fan; the first commercially produced self-propelled harvester in 1911 (also a Hill-side machine); and the first combine of steel in 1913.

4/ Phillips, op cit.

Many other machines were built in the late 1800s in California, but none of them were as successful as the Holt and Best machines. One of them used a corrugated threshing cylinder and concave but did not prove to be as successful as the toothed type, in general use since about 1830. Today's combines use the tooth-type for rice, and the rasp-bar cylinder for other grain.

It must be noted, however, that the first self-propelled combined harvester to be built was neither a Holt nor a Best. (Holt sold the first *commercially* produced self-propelled machine.) It was an interesting machine in that it used a straw-burning steam engine. It was surprisingly manoeuvrable for its size, but required seven men to operate it.

These early combines in California were built only on special order, and were generally too costly for popular use. It was not until the First World War when a labour shortage occured, that combines became widely accepted and began to be marketed "ready-made".

Meanwhile, a parallel development of a different combine type was going on in Australia. In 1843, a stripper-harvester was invented by John Ridley. It was a machine which stripped the kernels instead of cutting the stems but left the winnowing as a second operation. Although it was used relatively extensively, it was not improved until 1884. In that year Hugh Victor McKay, at Sunshine, Australia, perfected his stripper-harvester which by cleaning the grain after stripping, produced a clean grain sample in a once-over operation in the field. It was actually a Ridley stripper-harvester (which had never been patented) with a separator added.

McKay's machines were small and of light draft compared with the enormous California machines. Between 1884 and about 1910, roughly 10,000 of these machines and improved models were exported to the Argentine, attesting to its technical efficiency and popularity.

In 1901 Massey-Harris of Toronto, having studied a sample of the Sunshine combine, took up production of a very similar machine for export to both Australia and the Argentine. None of these machines were produced for domestic consumption. In 1904 International Harvester followed Massey's lead, with a machine of its own.

In 1910, after a number of years of development, Massey-Harris put their No. 1 Reaper Thresher on the market. This machine was horse-drawn, and the power for its mechanism came from one large ground-drive wheel. It used a reel-type table with a 10-foot cutter-bar similar to the California machines, and different from the "strippers" of Australia. The grain was elevated to the small threshing cylinder on a canvas belt conveyor, again different from the auger used by the "strippers". The grain and straw were delivered from the threshing cylinder to the straw walkers, and the grain was sieved and passed through a fanning mill to a grain bin. This machine was also designed mainly for export, with none for domestic consumption.

It should be stressed that although most of the operating principles of the combine were developed in the California machines, they were too big and expensive for general use. It was the small combines developed from the Australian stripper-harvester, through to the Massey-Harris reaper-thresher, that were bought in large numbers and eventually became the combine of today.

Around 1920, Holt pioneered the use of combines east of the Rockies where everyone had assumed that grain would have too high a moisture content to be combined because of the "humid" climate. Holt was followed shortly by International Harvester and, one or two years later, by nearly everyone else. Previous to that time, American manufacturers refused to "stick out their necks" to provide combines in the mid-West, "even though the would-be buyer offered to throw gold over the transom with his order".[5/]

In Canada, combining was adopted some years later. One of Massey-Harris' machines was sent in 1927 to the Agricultural Experiment Station at Swift Current, where it was tested and proven to be very successful. However, farmers were still not able to buy them in Canada. In 1923, a Saskatchewan farmer bought a combine in Kansas City and had it shipped to his farm. Through similar channels, five more were accumulated in Western Canada by the autumn of 1924, but by 1928, combines were being sold in the Prairie Provinces and the number of operating machines had increased to well over 3,000.

5/ E. J. Baker, Jr., "Combine Reflections", Implement & Tractor, Feb. 1, 1961, p. 36.

A technique which helped in the introduction of the combine in Western Canada was the use of "swathing". This is carried out by a swather, a machine which cuts the grain with a cutter-bar and lays it out in a windrow. The windrowed or swathed grain is left to dry and then picked up with the combine and threshed. This enabled the farmer to cut the grain sometime before it was ripe and thus get the crop in before the snow came.

Although the self-propelled combine came much earlier in California, the small combines, popular in the rest of North America, the Argentine and Australia, were not self-propelled until 1925. In that year H. V. McKay Pty Ltd., after much development work which actually began in 1909, commercially produced the Sunshine Auto-header. A Canadian firm, the Waterloo Manufacturing Co. Ltd. of Waterloo, Ontario, joined with H. V. McKay around 1924 to manufacture the "Sunshine-Waterloo one-man self-propelled combine thresher".

The gathering mechanism of this machine consisted of a comb with a reciprocating knife (cutter-bar); two augers, one behind the other, were back of the knife, and these carried the cut grain to the central elevator where it was carried up to the 10-ribbed-bar threshing cylinder and concave. This type was similar to today's rasp-bar cylinders. There were fans to direct an air blast across the sieves back of the concave. The straw was deflected out of the concave area onto the straw walkers. The whole threshing and cleaning mechanism was much like that on today's combines, with two collection points, one where partially threshed grain could be routed back to the cylinder for rethreshing, and one where clean grain could be elevated to the grain bin. The power-plant was a 32 HP, four-cylinder gas engine which drove both the threshing and pick-up mechanism and one wheel for propulsion.

Prior to the 1920s most combines were horse-drawn and later tractor-drawn, with ground-wheel drive for their threshing mechanism. With the introduction of the power-take-off or PTO on tractors in 1924, came the PTO-driver combine. These proved to be very popular and came to be used almost exclusively until the self-propelled combine began to establish itself on the market just before the Second World War.

Some of the technical improvements in the 1920s and 1930s included the steel frame and body, antifriction bearings, general adoption of V-belt drives and rubber tires, and a lighter machine.

In the early 1930s a few farmers in the Argentine had converted standard Massey-Harris Reaper Threshers into crude self-propelled combines by adding an engine. Massey noted this, and in 1936 development work was started on a self-propelled combine. Production of this machine, the No. 20 Self-Propelled Combine, started in 1938.

This machine was expensive and only the larger farmers could afford it. A smaller model, the No. 21 Self-Propelled Combine, was developed and put into production during and after the war.

Another type of combine was developed by Massey and marketed first in 1938. This was the scoop-table, straight-through combine, in which the threshing cylinder was almost as wide as the table (five feet wide, with six-foot table). The rest of the separating and cleaning mechanism was as wide as the cylinder. This allowed straight-through cutting and separation. One of their self-propelled machines built just after the war was of this type.

During the war, when the farm machinery companies were put on a quota basis, Joe Tucker of Massey-Harris convinced Washington that to satisfy the wartime demand for wheat, a "Harvest Brigade" of self-propelled combines was necessary. The Government thus released the necessary steel to Massey to build the combines, and in this way Massey was able to produce 500 self-propelled combines above their quota in 1944. These machines were sold to custom operators who under Massey supervision formed the Harvest Brigade. These machines were sent West in 1944 and harvested everything on a three-state front from Texas to the Canadian border. They proved to be excellent advertising for not only Massey-Harris but also for the self-propelled combine itself.

After the war the use of self-propelled combines increased rapidly. Today there are at least five major companies producing self-propelled combines in North America besides Massey-Harris (now Massey-Ferguson), and several European countries including Russia are also producing large numbers of them.

The pull-type, PTO-driven combine still has certain advantages over its progeny, the self-propelled combine. As early as 1925, one writer stated that "it is not logical from an economical point of view to duplicate the propelling apparatus on machines used only a few weeks each year, when the majority of the buyers already have tractors capable of pulling them".[6/] The same argument holds today. Pull-type combines are considerably less expensive than self-propelled ones of comparable size. In the United States, sales of pull-type machines had reached over 100,000 in 1950 from 4,000 in 1935, but this may have been part of the general interest in the combining principle and the general upturn in mechanized agriculture after the war. It was during this period that windrower and windrow pick-ups for combine platforms were developed. At the same time the canvas conveyors on platforms were replaced with less troublesome augers. Platform sizes ranged between five and twenty feet, but the smaller, under-seven-foot-width machines were most popular in Central North America.

After the war the trend to larger farms helped to justify the self-propelled combine, and the pull-type machine began losing ground. In Canada sales of pull-type combines varied between about 2,000 and 3,000 while self-propelled combines rose from about 5,000 to about 7,000, in the period 1960-67. On a regional basis, however, matters are a little different. While there is a clear trend away from pull-type combines in Ontario and Quebec, there is a less clear trend, but a trend nonetheless, toward pull-type machines in the West, especially Saskatchewan. There are several possible reasons for this.

With the advent of the 100 HP tractor to pull and power it, comes the possibility of producing very large pull-type combines comparable to the largest self-propelled models, but at close to half the cost. John Deere is already producing several models of high-capacity pull-type combines. Their model 106 has a 50-inch threshing cylinder. Although one of the disadvantages of the pull-type is its lack of manoeuverability compared with the self-propelled type, the difficulty can be overcome, at least for the farmer who now uses several combines, by using a small self-propelled machine to open up his fields and following with a large pull-type to combine the main part.[7/]

6/ Phillips, op. cit.

7/ Private correspondence with C.G.E. Downing, Director Engineering Research Service, Canada Department of Agriculture.

The other, and allied reason, is the practice of windrowing, which does not require a wide header to feed a large-capacity combine, and thus it decreases the advantage in manoeuverability of the self-propelled combine.

The Ontario pattern of sales may also possibly be explained in a recent note from John Deere. They make the observation that:

> Field shelling of corn in the U.S. Corn Belt with the self-propelled combine which required the development of a corn attachment has essentially doubled the market for self-propelled combines in the United States. Obviously, the advantage of a self-propelled machine which provides better vision and other conveniences for the operator has contributed to its increasing popularity in Canada.8/

The first statement may explain the decrease in popularity of the pull-type combine in Eastern Canada, as the number of acres of grain corn in Quebec and Ontario rose from around 400,000 acres in 1961 to around 800,000 acres in 1966.

There have been few basic changes in combine manufacture and design since the war. One major advancement, however, came just before 1949. Bulk handling of grain on the combine eliminated the sack sewer and jigger, thus cutting the labour requirements to one operator. Some of the technical and mechanical changes have included variable-speed drive, using extra heavy V-belts in adjustable-diameter sheaves, in order to give the combine stepless speed ratio changes. In the last 10 to 15 years, power steering was introduced. Massey-Ferguson introduced the rethreshing unit for the tailings or unthreshed heads which get past the cylinder, instead of elevating them up and back to the front of the cylinder. Cabs for driver comfort (the latest come with air conditioning) were also introduced.

There is a trend towards larger capacities again; up to 25-foot grain tables. Other trends include a move to increased use of on-the-go control of cylinder speed, concave spacing, etc.; and increased use of hydraulic controls, which has recently been aided by the introduction of hydrostatic drives for combines which replaces the V-belt and adjustable diameter sheaves. Hydrostatic

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8/ Private correspondence with J. C. Trimble: President, John Deere Limited, Hamilton, Ont., Oct. 30, 1968.

drive operates by simply connecting the engine to a hydraulic pump which pumps hydraulic fluid under high pressure to various hydraulic motors, which in turn drive the wheels, the cylinder, the reel and the other combine mechanisms.

Today's combines also come with many different attachments and in many different sizes. Corn harvesting attachments, which include special corn heads, for picking up the corn, and with modified threshing cylinders, rice combines, edible bean models and hill-side wheat combines, are all offered. Grain heads or tables vary in width from eight to twenty-four feet and engine horsepowers range between 55 and 130.

Conclusion

It may be seen now that the modern combine is the result of two lines of development: the large California combines from which are derived the modern combine's reaping and threshing mechanisms, the small Australian "stripper-harvester" from which came the concept of a combine of a size that most grain farmers could afford. These two lines merged in the 1930s and the result was the self-propelled combine in 1938. The self-propelled combine was so popular that farmers tended to forget the economic advantages of the PTO-driven pull-type combine, but more recently, there has been a move towards the pull-type in Western Canada.

It would appear that combine development took place almost entirely in North America (particularly California) and Australia. This is because of "damp harvesting conditions and uneven ripening of grain, the combine was not successful until it was adopted in California and Australia where conditions favour rapid and even ripening of grain. This would eliminate many of the European countries and the Eastern Asiatic Countries where mechanical threshing remained very primitive until recent years".[9/]

It might also appear from the context that the threshing and separating mechanism of combines has changed very little from the 1920s and 1930s when the use of combines first became widespread. It is true that only minor qualitative changes have taken place

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9/ From private correspondence with Mr. G. A. Wilson, Western Development Museum, Saskatoon.

since then, but some recent research indicates that a breakthrough is not far away. A combine, developed at Michigan State University, uses a conical threshing concave and conical beater. The crop is fed in the small end of the cone and almost 98 per cent of the grain is threshed out and falls through the perforations in the concave. The straw is then pushed out the large end of the cone, eliminating the need for a straw rack. It is reported that this machine uses less power and is smaller than the conventional combine.

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